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Optimal Testing Strategies for Genetically Modified Wheat

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ABSTRACT

A stochastic optimization model was developed to determine optimal testing strategies, costs, and risks of a dual marketing system. The model chooses the testing strategy (application, intensity, and tolerance) that maximizes utility (minimizes disutility) of additional system costs due to testing and quality loss and allows simulation of the risk premium required to induce grain handlers to undertake a dual marketing system versus a Non-GM system. Cost elements including those related to testing, quality loss, and a risk premium were estimated for a model representing a grain export chain. Uncertainties were incorporated and include test accuracy, risk of adventitious commingling throughout, and variety declaration. Sensitivities were performed for effects of variety risks, penalty differentials, re-elevation discounts, import tolerances, variety declaration, risk aversion, GM adoption, and domestic end-user.

Key Words: Segregation, Testing, Tolerance, Genetically Modified, Wheat, Risk Premium

HIGHLIGHTS

Biotech grains and oilseeds have become increasingly important in recent years because of their potential to provide agronomic benefits to producers and specific quality-based attributes to end-users. Development of testing, tolerance, shipping, and segregation strategies are imperative to commercial firms throughout the production and marketing supply chain to facilitate marketing in a dual system. Segregation strategies will be important to avoid adventitious commingling of grain and to ensure effective incentive schemes. Commercial and regulatory tolerance limits vary substantially across buyers, indicative that conformance will reside with tolerance policies.

The objective of this research was to evaluate the optimal testing strategy encompassing test application, intensity, and tolerance for a dual marketing system consisting of Non-GM and GM flows. A stochastic optimization model was constructed utilizing an objective function that maximizes portfolio utility (minimizes portfolio disutility) of additional system costs for a grain marketing channel handling two states of nature (Non-GM and GM). The model determined the optimal testing application, intensity, and tolerance to employ at country elevator receiving, country elevator loading, export elevator receiving, and export elevator loading subject to a specified tolerance at the end-user. Tests can be applied at any point in the marketing channel with varying discrete intensities and tolerances (.04% to 5%).

Summary of Results

The optimal testing strategy simultaneously determined test application, intensity, and tolerance that minimized the disutility of additional system costs for a portfolio of segregations. The model identified system costs through total costs across all bushels and Non-GM bushels. Various sensitivities were performed to determine how stochastic, strategic, parametric, and other variables affected optimal testing strategies, risks, and costs. Stochastic sensitivities included risk of adventitious commingling at first delivery, penalty differentials, and re-elevation/diverted GM discounts. Strategic sensitivities included import tolerance specifications and variety declaration. Parametric sensitivities included risk aversion and GM adoption. A final sensitivity evaluated the effect of a domestic versus import system.

Stochastic Sensitivities

The main benefit to performing sensitivities on stochastic variables was to assess changes in optimal testing strategies, risks, and costs from random probability distributions. Sensitivities of stochastic variables are examined in succeeding sections and variations are compared with base case results.

- **Adventitious Commingling at First Delivery.** Costs and risks increased as the rate of adventitious commingling at first delivery deviated from the base case due to the inability to distinguish GM from Non-GM content. Increased risk of adventitious commingling at first delivery increased total costs through increases in testing cost, quality loss, and risk premium. Probability of rejection at importer also increased, while the percentage of Non-GM flows decreased. Similarly, lower risk of adventitious commingling at first delivery increased total costs, albeit with decreases in testing and risk premium components. The lower risk case exhibited increases in quality loss and, thus, total cost due to no testing at country elevator receiving. Correspondingly, the probability of rejection at the importer increased and importer Non-GM flows decreased.

- **Penalty Differentials (Discounts).** Penalties varied from 0-10 c/bu for the low penalty case to 100-150 c/bu for the high penalty case at the importer. Total cost for all bushels trended upwards as penalties were increased. The most pronounced effect occurred in the risk premium, which increased from 0.33 c/bu for the low penalty case to 4.18 c/bu in the high penalty case, reflecting a higher cost/risk for non-conforming lots. Testing cost and quality loss exhibited similar increases. However, when costs were attributed to Non-GM bushels, total cost declined for the high penalty case compared to the base case. The percentage of Non-GM flows at the importer was 29 for the low penalty case, 48 for the base case, and 73.2 for the high penalty case. The probability of rejection at the importer decreased as penalties increased, providing evidence of the tradeoff between testing cost and seller risk.

- **Re-elevation and Re-elevation/Diverted GM Discounts.** Re-elevation and re-elevation/diverted GM discount cases were incorporated to reflect re-elevation costs at country and export elevator loading and discounts for diverting GM lots at country elevator loading and export elevator receiving and loading. For the re-elevation case, total cost decreased due to increased testing at country elevator receiving. The re-elevation/diverted GM discount case tested more intensively than the re-elevation case, increasing total cost relative to the re-elevation case, but decreasing total cost compared to the base case. Both cases decreased the probability of rejection at the importer from 2.83% in the base case to 1.78%, and increased Non-GM flows at the importer to 73.2%. Handlers/shippers required progressively larger risk premiums as re-elevation and re-elevation/diverted GM discounts were added, providing evidence that re-elevation and marketability of grain are critical factors.

Strategic Sensitivities

Strategic decisions by importers and commercial firms have implications for optimal testing strategies, risks, and costs in a system. The following sections examine sensitivities on strategic variables, and variations are compared with base case results.

- **Import Tolerance Specifications.** Importers designate tolerances based on government mandates and their preferences. Firms may specify tighter tolerances then necessary based on consumer preferences and value-added market potential for differentiating products. Importer tolerances of 0.5%, 2%, 3%, 4%, and 5% were examined relative to the base case tolerance of 1%. In general, total costs decreased as tolerances were loosened with the exception of the 4% tolerance, which slightly increased due to a different testing strategy. Testing costs increased for the 0.5% case and then decreased for tolerances looser than the base case. Quality loss decreased as tolerances were loosened with the exception of the 4% tolerance, which slightly increased. As expected, the risk premium required for handlers/shippers significantly decreased with a looser tolerance specification. This reveals that loosely specified tolerances for GM could be attained with little additional risk imparted to the handler/shipper. Ironically, the percentage of Non-GM flows at the importer decreased as tolerance was loosened. This was mainly due to large diversions at country elevator loading from variety risk since testing was not conducted at country elevator receiving for 2%, 3%, 4%, and 5% cases. The probability of rejection at the importer generally decreased when tolerance was tightened and increased when tolerance was loosened; however, it decreased from the 2% case to the 3% case and again from the 4% case to the 5% case. This is due to similar testing strategies for 2% and 3% tolerances and 4% and 5% tolerances and the corresponding decrease in tolerance within each range.

- **Variety Declaration.** Contract mechanisms were adopted to elicit information from farmers regarding the GM content of their grains. The level of farmer variety declaration assumed a *Risk Triangle* distribution representing minimum, most likely, and maximum values. Three models were developed including a 40-50-60%, 65-75-85%, and 80-95-100% case to indicate the probability that farmers will tell the truth. Higher levels of variety declaration decreased total costs across all bushels. Total cost across Non-GM bushels also decreased except for the moderate case where they slightly increased due to the percentage of Non-GM flows at the importer. The total cost spread between the base case and the high variety declaration case was 6.5 c/bu across Non-GM bushels. It can be viewed as the value to implementing contract mechanisms for variety declaration. Testing cost and quality loss generally declined for higher levels of variety declaration indicating that less intensive testing strategies sufficiently reduced adventitious presence of GM. The risk premium also slightly declined from 2.42 c/bu in the base case to 2.34 c/bu, 2.26 c/bu, and 2.19 c/bu for the low, moderate, and high variety declaration case, respectively. At the importer, Non-GM flows generally increased for higher levels of variety declaration, and the probability of rejection generally decreased although the moderate case experienced a slight increase and decrease in probability of rejection and Non-GM flows, respectively.

Parametric Sensitivities

Sensitivities on parametric variables assess impacts to optimal testing strategies, risks, and costs from system changes including risk aversion of handlers/shippers and the rate of GM adoption. The successive sections examine these changes and compare variations with the base case.

- **Risk Aversion (η)**. The risk parameter η was varied from 0.5 in the base case to 0.4 and 0.9 to represent less risk averse and more risk averse handlers/shippers, respectively. The optimal testing strategy intensified as risk aversion increased indicating that more risk averse firms prefer testing to quality loss. Correspondingly, testing costs progressively increased and quality loss steadily decreased for higher levels of η. The risk premium required to compensate handlers/shippers decreased from 2.42 c/bu in the base case to 1.63 c/bu for the less risk averse case and increased to 3.28 c/bu for the more risk averse case. The probability of rejection at the importer increased for the less risk averse case and decreased for the more risk averse case. Total costs across all bushels and Non-GM bushels declined for higher levels of η. Across Non-GM bushels, the less risk averse case had a total cost of 43.3 c/bu compared to 15.83 c/bu the base case and 9.19 c/bu for the more risk averse case. The large disparities resulted from quality loss and were further exacerbated by the percentage of Non-GM flows at the importer, which significantly increased for higher levels of risk aversion.

- **GM Adoption.** Varying levels of GM adoption could proliferate in the case of GM wheat depending upon import restrictions, agronomic benefits, and consumer preferences. GM adoption rates were varied for no variety declaration and variety declaration scenarios to identify system implications.

  Three cases including 10%, 25%, and 30% GM adoption were examined with no variety declaration; however, only 10% and 25% cases provided feasible results. The 10% case employed a less intensive testing strategy that resulted in lower testing costs, quality loss, and total costs across all and Non-GM bushels. In addition, the percentage of Non-GM flows increased from 48% in the base case to 57.8%. The 25% case tested the same as the base case and resulted in higher testing cost, quality loss, and total cost when measured across Non-GM bushels, partially due to 39.1% of flows being Non-GM at the importer. The risk premium and probability of rejection at the importer both increased for higher GM adoption rates, indicating that it becomes more challenging to remove adventitious presence of GM in a no variety declaration. The 30% case was unable to achieve segregation of Non-GM and GM flows at a cost less than the underlying value of the commodity. This reveals that GM adoption rates greater than 25% necessitate a system of variety declaration with contract mechanisms.

  The rate of GM adoption with variety declaration was varied to 25%, 50%, 60%, 70%, and 75% to simulate impacts on the system. The 75% case was infeasible indicating that a GM adoption rate greater than 70% would necessitate an alternate system of testing and segregation and/or identity preservation (IP) to adequately maintain segregation of GM and Non-GM flows. As the rate of GM adoption increased, testing was less intensive and quality loss generally increased with the exception of the 25% case where quality loss decreased. Total costs across all and Non-GM bushels generally increased as the GM adoption rate increased except for the 25% case where total cost declined. The risk premium initially decreased for the 25% and 50% cases, and then increased for the 60% and 70% cases because disutility was lower for 25% and 50%, and higher for 60% and 70% compared to the base case. The probability of rejection at the importer initially decreased for the 25% case and then progressively increased for 50%, 60%, and 70% cases. Conversely, the percentage of Non-GM flows at the importer increased for the 25% case and then progressively decreased for 50%, 60%, and 70% cases. The rationale for lower importer rejection, risk premium, and total costs for the 25% case and lower risk premium for the 50% case may be attributed to discrete choice and utility theory.

Implications

Development and commercialization of GM crops continues to challenge the current functions and operations of the grain marketing system. With the anticipated commercialization of GM wheat, these issues remain increasingly important. The research defines several relationships between optimal testing strategies, risks, costs, and different variables impacting the dual marketing system. The impacts of stochastic, strategic, parametric, and other variables on the optimal testing strategies, risks, and costs are shown and evaluated. Implications for public and private sectors are summarized in the following sections.

There are several implications for the public sector. First, a system of testing and segregation can efficiently provide end-users differentiated grain shipments to meet consumer requirements at a low cost. While nil tolerances are unattainable, GM content can reasonably be assured for current import specifications of 0.5% or above. Second, grain uniformity and quality deviations existing in the marketplace are minimized due to quality loss applied at the end-user. Sellers view deviations from zero percent GM contamination as an implicit cost; thus, more rigorous testing ensues thereby reducing GM content in Non-GM shipments. Third, consumer differentiation amongst value-added products necessitates a system of testing and segregation to properly allocate Non-GM and GM flows.

Several private sector implications exist.

- A system of testing and segregation drastically reduces cost when compared to an IP alternative. IP entails increased monitoring and documentation through production, storage, transportation, and handling phases.
- With rapid advancements in testing technology, costs and risks will progressively decrease.
- Risk premiums evolve to compensate grain handlers for added risks of a dual marketing system versus a Non-GM system.
- Adventitious presence resulting from variety risks will encourage grain handlers to adopt a system of contract mechanisms.
- Additional penalties encourage handlers/shippers to test more intensively to avoid quality losses.
- Import tolerance defines testing strategy and accompanying costs and risks.
- More and less risk averse grain handlers tradeoff known testing costs for indefinite quality loss.
- The rate of GM adoption has a significant bearing on the viability of the defined system of testing and segregation. GM adoption of greater than 25% necessitates variety declaration mechanisms. With variety declaration, GM adoption of greater than 70% provides cost prohibitive results and thus necessitates an alternate form of testing and segregation and/or IP.

Optimal Testing Strategies for Genetically Modified Wheat

William W. Wilson, Eric J. Jabs, and Bruce L. Dahl*

INTRODUCTION

Biotech grains and oilseeds have become increasingly important in recent years because of their potential to provide agronomic benefits to producers and specific quality-based attributes to end-users. Concurrent with the adoption of transgenic grains, development of genetically modified (GM) wheat has evolved and GM varieties may be available by 2005.

Development of testing, tolerance, shipping, and segregation strategies are imperative to commercial firms throughout the production and marketing supply chain to facilitate marketing in a dual system. Testing procedures involve detection of genetic modification and the determination of quality and composition in an attempt to assign a component price. Shipping procedures will vary depending upon the investment in infrastructure, which currently is oriented towards high-volume, low-cost homogenous commodity flow. Segregation strategies will be important to avoid adventitious commingling of grain and to ensure effective incentive schemes. Commercial and regulatory tolerance limits vary substantially across buyers, indicative that conformance will reside with tolerance policy.

This report addresses production and marketing supply chain participants, which ultimately includes the entire supply chain: input suppliers, production, handling, processing, market distribution, and the consumer. Alternative scenarios, encompassing testing location, method, cost, risk, contract liability, and specified tolerance are evaluated to determine optimal strategies. Ultimately, this report analyzes economic costs and risks associated with testing, segregation, and the establishment of an optimal tolerance.

A stochastic simulation model of a system cost function is utilized to jointly determine optimal testing strategies for commercial and regulatory applications for GM commodities including GM wheat. The model is developed to compare costs and risks for a vertically integrated firm with a dual (GM/Non-GM) marketing system and jointly determines optimal test application, intensity, and tolerance. Effects of critical factors including testing costs and accuracies, quality loss, price differentials in different market segments, supply-chain costs, and/or spatial considerations are examined to determine their effects on optimal strategies.

The model and analysis include: 1) evaluation of various supply chain testing points according to frequency, type, place, and cost; 2) definition of the system and cost function to allow alternative testing strategies at different stages of the marketing system; and 3) assessment of quality loss costs resulting from non-conformance. The major contributions of this study to the evolving literature on marketing GM crops are: the quantification of risks and costs using a systems approach to the grain marketing system. In addition, we incorporate a Taguchi Loss Function and the probability and distribution of adventitious presence in the analysis.

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BACKGROUND AND PREVIOUS STUDIES

Supply chain coordination plays an integral role in the production, handling, storage, and export of GM grain. Effective supply chain management for GM grain relies on a multitude of factors including testing and sampling procedures, segregation practices, identity preservation (IP) techniques, logistical strategies, and conformance to tolerances in order to ultimately satisfy consumer demand. An increasing amount of research has been conducted on segregation and IP in response to the exportability of transgenic grains to importing countries with specified tolerances. This section provides a synopsis of these studies.

Process Verification

The U.S. Department of Agriculture, Grain Inspection, Packers and Stockyards Administration (USDA-GIPSA) proposed a new process verification program designed to meet the marketplace's rapidly evolving needs. The proposal is under review and would offer a Process Verification Service similar to what is already available in the Agricultural Marketing Service for livestock. Process verification provides producers, marketers, suppliers, and processors alike with third party verification of their quality processes and standards in an effort to ascertain buyers and sellers of marketing claims, such as type, production practice, and quality attributes. It is based on ISO 9000 principles, an internationally recognized set of quality standards, to ensure international objectivity and to provide a means to conduct a document review, review audit, conditional audit, and surveillance audit. GIPSA, recognized internationally for reliability and integrity, will provide technical knowledge through its grain expertise and integrity through mandatory auditor certification by the American Society of Quality (ASQ). Collectively GIPSA, and more broadly USDA, will provide a "USDA Certification" label to enhance buyers' confidence in process verified products, whether domestic or foreign (USDA-GIPSA, 2002a,b).

Segregation

Segregation is the isolation of like products with particular attributes to avoid commingling. Unlike IP, the identity of the grain is lost once it is accumulated with like products (Sonka, Schroeder, and Cunningham). Segregation has evolved in response to international market acceptance of bio-engineered products and the lack thereof. Coexistence of transgenic grain and non-transgenic grain has evoked the supply chain to segregate commodities such as high lysine corn and high oleic soybeans to ensure added value beyond the farm gate (Sonka, Schroeder, and Cunningham). As thresholds are revolutionized in the biotech industry, strict purity limits may be instituted requiring totally distinct handling systems to conform to regulations (Sonka, Schroeder, and Cunningham).

Although considerable debate has endured about segregation, the feasibility is questionable given negligible premiums for non-transgenic grain, adoption rates, storage, testing, and logistical implications. Initially, a survey of elevator managers dispersed throughout the United States, evoked a substantial negative connotation about segregation benefits, costs, and/or risks, but a recent survey conducted by the American Corn Growers Association rebuked earlier connotations. The survey of 1,149 elevators in 11 Midwestern states conveyed that more than half of grain elevators preferred segregation of GMO and Non-GMO grains this year, and in addition one-fifth offered premiums for Non-GMO corn and/or soybeans. The rationale for this rebuttal can be attributed in part to the Starlink corn incident, which solicited widespread fears associated with allergic reactions, and the reduction in export sales due to consumer confidence issues (Konsor). Ultimately, segregation will depend on premium incentives, added costs, and the evolvement of the international market outlook on transgenic grain.

Additional system components need to be implemented to facilitate the full adoption of biotech grain (Sonka, Schroeder, and Cunningham). A key system component includes development of transportation and handling infrastructure albeit with huge investment, which exasperates long-term industry payoff perceptions. Compounding the issue is that transportation and handling infrastructure has been historically characterized as highly competitive with very narrow margins. Currently, production and marketing for major commodity crops is oriented towards providing maximum value through low-cost delivery of massive amounts of homogenous grains and oilseeds; consequently, evolvement of a dedicated channel has lagged that of its counterpart (Sonka, Schroeder, and Cunningham). In the future, output trait enhancement oriented towards value-chain participants may inundate the industry forcing logistically distinct channels of transportation in addition to segregation to fully realize value. Complementary to infrastructure evolvement will be concurrent developments in measurement technology and dynamic underlying investment analysis (Sonka, Schroeder, and Cunningham).

Identity Preservation

Numerous studies address identity preservation (IP) costs within the supply chain and the factors that comprise them. Buckwell, Brookes, and Bradley define IP as a system of management and trade that allows the source and nature of materials to be identified as they move through the supply chain. Wilcke refers to IP as separate storage, handling, and documentation of separation; and Lin, Chambers, and Harwood define it as a production-handling-distribution system by which crops are required to be kept separate to avoid commingling during planting, harvesting, loading and unloading, storage, transportation, and manufacturing in order to preserve the crops' identity in terms of the end-use quality genetic makeup or a unique production process. Sonka, Schroeder, and Cunningham define IP as a coordinated transportation and identification system to transfer product and information that makes the product more valuable; and Dye refers to it as a traceable chain of custody that begins with the farmer's choice of seed and continues through the shipping and handling system. Irrespective of the definition of IP, it remains a formidable exercise unless the premiums extracted from the marketplace exceed the costs incurred. Inherent to IP are the additional costs in a variety of dimensions including production, storage, handling, and logistics (Kalaitzandonakes, Maltsbarger, and Barnes).

Identity Preservation Cost

Identity preservation results in two general categories of additional costs: direct and indirect (hidden) costs (Kalaitzandonakes, Maltsbarger, and Barnes). The increased need for market coordination between buyers and sellers, changes in operations due to newly adopted product identity practices, and increased risks and liabilities stemming from threshold conformance at destination comprise direct costs. Overwhelmingly, threshold limits govern the rigorous nature of an IP system; thus, they comprise the largest portion of direct costs. Indirect or hidden costs result from the underutilization of production, storage, and transportation assets (Maltsbarger, and Kalaitzandonakes). Transportation assets and storage facilities are discrete units, exacerbating IP costs due to their discontinuous or less fungible product stream nature.

Maltbarger and Kalaitzandonakes examined empirical data from three case study elevators (representing a small, medium, and large) functioning within the Midwest. Five efficient high oil corn IP scenarios ranging in volume from 100,000 to 500,000 bushels delivered during harvest and via buyer call while adhering to a 5% threshold are used to estimate costs. Post-harvest IP costs and their variability relative to selected shifters both exogenous and endogenous to the firm were derived. Total IP costs averaged 35 c/bu and ranged from 19.85 c/bu to 52.11 c/bu for the first case representing a medium elevator with 500,000 bu of high oil corn during peak harvest and a large elevator with 200,000 bu of high oil corn via buyer call, respectively. Total costs for the direct farmer network ranged from 9.98 c/bu to 27.99 c/bu for 500,000 bu of high oil corn during peak harvest and 100,000 bu of high oil corn via buyer call, respectively. The results highlight that even for a loose threshold, IP costs can be significant; particularly hidden costs (efficiency losses) which comprise, on average, 55% of IP cost and range from 29% to 75%.

The results indicate that IP costs are highly subject to volume and the physical configuration of assets, which suggests that scale economies are not present within the modeled supply chain. In addition, delivery options impact cost; for example, the buyer call reduces indirect cost as it pertains to underutilized elevator storage, but has a corresponding increase in coordination cost and storage premium. Furthermore, transportation mode choice and direct or intermediate supply chain utilization affect IP costs resulting in a direct relationship between cost and miles for direct delivery and an increase in efficiency when transporting via rail (truck) for long (short) distances in the intermediate delivery.

Lin examines the economics of segregating U.S. non-biotech corn and soybeans for shipments to Japan, the primary non-biotech export market for U.S. grains and oilseeds. Estimations of price premiums that buyers in the U.S. domestic and Japanese export markets are willing to pay for the 2000 and 2001 crops are explored. Additionally, implications are drawn from non-biotech premiums paid by both U.S. domestic and Japanese export markets in relation to the cost of segregation. Finally, an analysis of who bears the cost is examined.

Non-biotech, IP corn constitutes 1-2% of U.S. corn production while non-biotech, IP soybeans account for 2% of domestic soybean production. The majority of non-biotech corn and soybeans, approximately 90%, is exported to Japan through IP techniques. Underlying Japan's interest in non-biotech products is changing sentiment among consumers and government imposed labeling restrictions on 26 food items. Domestically, non-biotech corn and soybeans have been used in food processing firms such as Gerber, Heinz, Bestfoods Inc., and Frito-Lay Inc.

Japanese buyers' specification of a 95% purity requirement for non-biotech corn can effectively be met by patterning corn segregation after high oil corn (HOC) handling procedures although other methods exist such as the Association of Official Seed Certifying Agencies' (AOSCA) 99% purity level plan, which allows no more than 1% biotech. In addition, Cargill segregates non-biotech corn under *Innovasure*; a process-based identity preserved system albeit without a specified tolerance. In contrast, the identity preserved system for soybeans has followed the more rigid, Synchrony-treated soybean (STS) requirements. STS soybeans are a non-biotech, herbicide-tolerant variety developed by DuPont and marketed by ADM, Protein Technologies, and various grain companies. A purity level of 98% to 99.9% characterizes the STS IP program; however, in 2001 STS lost its appeal because of its biotech content rigidity. Currently, a non-STS identity preserved system patterned after HOC is being adopted for soybeans to meet threshold requirements.

The segregation costs presented are extracted from a University of Illinois study, which estimated segregation costs for 84 U.S. handlers of specialty grains and oilseeds. In the study additional segregation and handling costs for handling HOC and STS were 6 c/bu and 18 c/bu, respectively (Bender et al.). Lin, Chambers, and Harwood. examine the various costs unique to segregation including additional costs of storage, handling, risk management (i.e., conformance risk), analysis and testing, and marketing, along three points in the marketing chain including country elevator, sub-terminal, and export elevator. Segregation cost for non-biotech corn from the country elevator to export elevator was estimated at 22 c/bu if the segregation follows the HOC system (Lin, Chambers, and Harwood). In comparison, other researchers in the grain handling industry have estimated segregation costs at 20 c/bu (Miranowski et al.; Lence, and Hayes; Moss, Schmitz, and Schmitz; and Krejci). Non-biotech soybeans patterned after HOC and STS resulted in additional costs of 18 and 54 c/bu, respectively. The segregation costs reported reflect the cost associated with the needed adjustments or modifications to accommodate non-biotech commodities and include both real and hidden costs, estimated at two-thirds and one-third, respectively (Lin, Chambers, and Harwood).

Additional costs that are not inclusive of previous estimations are added freight expense, and producer premiums and incentives. Freight expense surcharges are assessed to volumes less than 8,000-9,000 tons and are unique to corn (13 c/bu) where complications arise from multiple biotech events and the existence of varieties that have not been approved by importing countries. In contrast, soybeans typically do not incur additional freight expense because herbicide-tolerant soybeans are the only approved biotech trait (Lin, Chambers, and Harwood).

According to USDA's "Value Enhanced Grain Survey" performed by the National Agricultural Statistics Services' *Illinois Market News*, producer premiums and incentives offered to producers for non-biotech corn ranged from 8 to 10 c/bu for the 2000 crop and approximately 10 c/bu for the 2001 crop. Non-biotech soybean price premiums were 15 to 20 c/bu for the 2000 crop and 20 to 25 c/bu for the 2001 crop (USDA-NASS). Total segregation cost for non-biotech soybeans from the U.S. farm gate to final destination in Japan is approximately 62 c/bu and 40 c/bu for the 2000 and 2001 crops, respectively; whereas total non-biotech corn segregation costs are approximately 45 c/bu for both cropping years. These estimates are reflective of all factors pertaining therein to segregation cost including producer premiums and incentives, handling costs at country elevator, sub-terminal and export elevator locations, and transportation considerations (Lin).

The demand price elasticity for non-biotech commodities ultimately determines who will bear segregation costs. Inelastic demand for non-biotech commodities is supported by strong consumer preferences for non-biotech, a lack of substitutes, and/or the nature of a commodity's market demand. Lin examines the willingness of Japanese buyers to bear the additional cost of segregation and shows that Japanese buyer premiums covered 93-111% and 89-111% of the 2000 and 2001 non-biotech corn crop, respectively, and 85-94% and 71-77% of the 2000 and 2001 non-biotech soybean crop, respectively (Lin). These estimates infer that demand for non-biotech commodities in Japan is inelastic, although less than perfectly inelastic. Inferior substitutes and inelastic demand for food-grade corn and soybeans underscores the inelasticity of demand for non-biotech products and allows U.S. grain handlers to pass on the majority of segregation costs to the Japanese market; however, U.S. grain handlers, exporters, and IP producers bear remaining costs not borne by Japanese buyers.

Seed Purity is the foundation for segregating GM from Non-GM grain and is attained through quality assurance programs such as the AOSCA and/or third party services. Although 100% purity is unattainable, it can be approximated at 99.8% to 99.9% for soybeans due to its self-pollination nature and approximately 99% for corn due to its cross-pollination nature. Additional seed purity can be obtained for corn by: 1) increasing isolation distances between seed-producing or contaminating fields; 2) planting to ensure different silk and pollen release among fields; 3) increasing the number of all-male border rows in seed-producing corn fields; and 4) manually roguing fields to remove undesirable variations.

If the farmer chooses to plant both GM and Non-GM varieties, he or she will need to take appropriate measures to mitigate contamination risk. Planters need to be sufficiently cleaned between GM and Non-GM planting runs to prevent inadvertent commingling of seed. Planter cleaning for 99% and 99.9% purity is 15 and 40 minutes for an 8-row planter, respectively, and 25 and 55 minutes for a 12-row planter, respectively (Hanna and Greenlees). Assuming the value of farm labor is $15 per hour, the total cleaning cost would be less than $15 between GM and Non-GM production runs. Coordination of GM and Non-GM runs would further reduce planter cleanout cost to virtually nil when configured on a per bushel basis. The growing phase entails discouraging cross-pollination in transgenic varieties such as corn and, potentially, available commodities such as wheat; however, soybean contamination risk is nil because of self-pollination. Practices tantamount to those of seed purity should be followed including temporal, spatial, roguing, border, and isolation zone considerations (Bullock, Desquibet, and Nitsi).

The harvesting phase presents additional contamination possibilities because of internal cleanout or flushing costs associated with the combine when alternating between GM and Non-GM fields. The first procedure is detailed in a video produced by South Dakota State University, which shows two people taking approximately four hours to remove literally every kernel of grain. Alternatively, the operator can flush the combine via two steps including light cleaning and harvesting 60 to 70 bu of the Non-GM variety to obtain approximately 99.8% purity (Greenlees and Shouse). The cost of the two alternative methods is disparate; the first method results in a total cost of $120 assuming labor is $15 per hour, while the second method results in a total cost of $18.85 assuming it takes two laborers fifteen minutes to clean the combine and the 70 bu is discounted at 15 c/bu. Currently, contracts between farmers and grain handlers recommend the use of the second method. For example, Consolidated Grain and Barge Company (CGB) and Protein Technology International Inc. (PTI) stipulate that, “Combine was blown or swept clean and visually verified to be free of all other grain and soybeans,” and Archer-Daniels-Midland (ADM) verifies STS variety purity with the farmer statement, “I used reasonable care to clean all harvesting equipment to ensure it was free from any contaminants to the STS grain" (DuPont Specialty Grains, 2000a,b).

Transportation off the farm costs include sweeping the truck clean and implicit harvesting costs if a truck shortage is realized due to excessive queuing at the country elevator. Transportation from the country elevator to a domestic processor or an export elevator is done primarily via rail, whereby federal grain inspectors issue each car a certificate, called its origin grade (Bullock, Desquibet, and Nitsi). River elevators out of the gulf ports handle approximately 75% of the whole grain U.S. corn and soybean exports (USDA-FAS, 2000a,b; USDA-FGIS, 2000). Consequently, additional barge costs are incurred because river elevators typically move grain from truck to barge; therefore, they incur a barge cleaning cost, which is mandated by law and is approximately $300. Conversely, export elevators incur a minimal segregation cost tantamount to that of a country elevator associated with segregating varieties and grades among shipping and storage bins (Bullock, Desquibet, and Nitsi). Grain not exported in bulk form is transported to domestic processors where GM and Non-GM segregation is sustained through dedicated facilities or staggered production runs (Archer Daniels Midland Company).

Testing occurs throughout the supply chain, but typically the first testing point is at the country elevator to detect presence of GM or Non-GM grain in a declared variety. Testing intensity will depend upon the number of events that have to be recognized to validate GM content. Currently, soybeans have been granted 11 transformation events for environmental, feed, and food release in the U.S., but only glyphosate-resistant soybeans are presently available for commercial planting. In contrast, corn has been granted 16 transformation events, many of which are available for commercial planting, exacerbating testing costs (Bullock, Desquibet, and Nitsi). GM events can be detected either quantitatively or qualitatively through an array of testing methodologies including herbicide tolerance bioassay, Immuno assay, which encompasses Enzyme Linked Immunosorbant Assay (ELISA) and strip test, and Polymerase Chain Reaction (PCR). Selection of an appropriate testing method is contingent upon the number of events to detect, time constraints, sample size, and result specification.

Bullock, Desquibet, and Nitsi estimate testing costs at the handling stage for export of Non-GM soybeans and Non-GM corn to Japan by CGB. The soybeans are delivered to the river elevator via truck where two strip tests are used per truck. The soybeans are stored in shipping bins until loaded onto a barge, a representative sample is obtained, and a quantitative ELISA test is performed. Finally, the barge unloads into an ocean vessel at New Orleans where samples are drawn and ELISA tests are reiterated. Total testing costs are 2.31 c/bu; however, corn testing costs increased to 4.87 c/bu due to PCR versus ELISA testing and the requirement to test for additional events not approved for import in the European Union (EU) or in Japan.

Production of GM or Non-GM grains to meet importer specifications ultimately begins with the farmer; consequently, quality incentives and contracts must be offered to offset additional incurred costs and risks. Typically, grain handlers stipulate accepted farm production practices, premiums, and the delivery window with the farmer; for example, CGB, ADM, and PTI all offer grower contracts via the OSCAR internet-based contracting system developed by DuPont Specialty Grains, where approximately 800,000 acres of Non-GM STS soybeans and 700,000 acres of Non-GM soybeans are contracted (DuPont Specialty Grains 2000c,d). Farm premiums vary between $0.10 and $0.30 depending upon variety and contract obligations; for example, ADM offers elevators a $0.25 premium for STS soybeans, whereby a $0.20 premium is allocated to the farmer (Archer Daniels Midland Company). Another example is the 22 c/bu premium received for Non-GM soybean shipments to Japan; 10 c/bu premium is allocated to the farmer who must account for extra costs related to cleaning, logistics, and technology, and 12 c/bu is available for the elevator to compensate for additional testing and reshuffling costs (Bullock, Desquibet, and Nitsi).

In the absence of an internationally recognized set of rules, nations will establish and contour domestic trade regimes to address consumer concerns. Inevitably, huge disparities arise among trade nations; thus, an effective Identity Preserved Production and Marketing (IPPM) system may be needed to track product attributes and facilitate trade (Hobbs, Kerr, and Phillips). Currently, there is a wide range of IPPM systems operating in Canada and around the world varying in their degree of specificity although commonalities exist among IPPM systems. All IPPM systems start with certified seed, are handled and transported through special arrangements (e.g., containers, dedicated trucks), and segregated at the handler or processor for movement to the wholesaler, processor, or retailer in an attempt to preserve value-added attributes (Hobbs, Kerr, and Phillips). The value-added attributes inevitably will be ascertained through third party verification and certification because of incentives to cheat. The principal-agent problem is readily apparent because *ex post* verification may not be possible or costly; however, the incentive will hinge on a subjective assessment of detection and penalties relative to potential gains. Third party verification will assure credibility and integrity of the IPPM system and ascertain the buyer and seller of process attributes (Hobbs, Kerr, and Phillips).

A related study by Smyth and Phillips estimates costs, explores reasons, and evaluates government statutes regarding the establishment of an IPPM. The additional cost of operating an IPPM for small niche market products, excluding other endogenous variables that raise cost such as testing and conformance risk, is estimated at 15-20% above the cost of moving conventional products through a supply chain.

Handling Risk

A few studies have tried to quantify risks of adventitious commingling in handling. Casada, Ingles, and Maghirang explore residual and cross-contamination of grain during handling to address the imminent evolvement of segregation strategies to properly segment GM and Non-GM grain to meet stringent threshold requirements. The USDA, Agricultural Research Service (ARS) utilizes a GMPRC Engineering Research Unit (55,000 bu grain unit) to determine IP procedures for commercial grain storage facilities and contamination levels that may be realized (Casada, Ingles, and Maghirang). The research elevator has two legs, each with a capacity of 3,000 bu per hour. Cross contamination and residual estimates were evaluated under three scenarios: 1) red wheat followed by white wheat; 2) yellow corn followed by white corn; and 3) corn followed by wheat; however, only the second scenario has been analyzed thus far. The preliminary residual results indicate that contamination in the elevator boot and receiving pit was 0.21% and 0.04%, respectively inferring a total contamination level of 0.25%; however, this figure represents potential contamination since much of the grain will not dislodge and contaminate subsequent grain lots.

A curve of contamination percent versus time after second grain commencement was constructed and normalized based on contrasting grain sample estimates and the bu percentage of leg elevation per hour, respectively. Three consecutive replications unequivocally indicate that only the first 15 to 20 bu of grain were contaminated at a level greater than 1% and only the first 40 to 50 bu of grain were contaminated at a level greater than 0.5%. The study reveals that the conformance to a rigorous tolerance limit at the elevator location is attainable through pragmatic clean-out procedures, which rely on employee adherence to an established protocol.

Management practices such as dedicating facilities and designating biotech delivery dates may enable the elevator to prevent commingling, minimize queues, and maintain a clean environment for effective crop segregation. The segregation of biotech commodities raises logistical concerns with respect to increased transportation costs resulting from the anticipated migration from unit train shipments towards smaller unit shipments such as single rail cars. According to the North American Grain Exporters Association, a 5% biotech threshold presents modest increases, but more stringent thresholds, which embark on IP and evoke substantial costs (Shoemaker et al.).

In addition to these studies, numerous others quantify IP and segregation costs for a range of commodities utilizing different methodologies including surveys of elevator managers (Nelson et al.; Jirk; Dahl and Wilson; Wilson and Dahl, 2001), cost accounting methods (Askin; McPhee and Bourget; Hurburgh et al.; Bullock, Desquibet, and Nitsi; Sparks Company.; Smyth and Philips) and simulation (Hermann, Boland, and Heishman; Maltsbarger and Kalaitzandonakes). I.P. segregation costs range from 1 to 72 c/bu in these studies and are summarized in Table 1.

Testing Methods

Testing procedures vary widely and may be conducted during several stages of production and movement of agricultural product through the supply chain. Compliance to a certain threshold level of genetic material is a major concern for supply chain management and efforts to mitigate risks will undoubtedly evolve to ascertain conformance. These efforts will proliferate through the evolvement of testing protocols and procedures. Factors to consider when testing include cost, limit of detection, time required to complete the test, and the level of technical skill and knowledge required to conduct the test (Stave and Durandetta; Sonka, Schroeder, and Cunningham). An overview of testing apparatus, required time, and costs measured at 95% accuracy are summarized in Table 2.

Table 1. Previous Studies on IP and Segregation Costs

Researcher	***Methodology/Scope of Analysis***	***Estimated Cost of Segregation/IP***
Askin, 1988	Econometric model of costs for primary elevators	Increase of 2 grades handled increased costs < 0.5 c/bu
Jirik, 1994	Survey of Elevator Mgrs. and Processors	11 to 15 c/bu
Hurburgh et al., 1994	Cost Accounting Model for High Oil Soybeans	3.7 c/bu
McPhee and Bourget, 1995	Econometric model of costs for terminal elevators	Increasing grades handled increases operating costs 2.6%
Hermann, Boland, and Heishman, 1999	Stochastic Simulation Model	1.9 to 6.5 c/bu
Maltsbarger and Kalaitzandonakes, 2000	Simulation Model for High Oil Corn	1.6 to 3.7 c/bu
Nelson et al., 1999	Survey of Grain Handlers	6 c/bu corn, 18 c/bu soybeans
Bullock, Desquibet, and Nitsi, 2000	Cost Accounting	30 to 40 c/bu soybeans
Dahl and Wilson, 2002	Survey	25 to 50 c/bu
Wilson and Dahl, 2001	Survey of Elevator Mgrs for Wheat	15 c/bu
Smyth and Phillips, 2001	Analysis of GM IP system for Canola in Canada, 1995-96	21-27 c/bu
Gosnell, 2001	Added transportation and segregation costs for dedicated GM elevators	15-42 c/bu High throughput 23-28 c/bu Wooden elevators
Sparks Companies 2000		Non-GM Canola 38-45 c/bu Non-GM Soybeans 63-72 c/bu

Source: Wilson and Dahl, 2002.

Table 2. Testing Method, Cost, Limit of Detection, and Duration

Event	*Testing Method*	*Testing Cost Per Sample*	*Limit of Detection*	*Testing Duration*
Canola				
35S, CP4/EPSPS,NPT11	PCR	$25/1000 seeds	Qualitatively detects 1 out of 1000 seeds, Quantitatively detects .01% GM presence	3 Days
RR, Liberty Link	Herbicide Bioassay	$30/600 seeds	Depends upon minimum herbicide tolerance requirements	7 Days
Corn				
35S, NOS, CP4/EPSPS, Cry1Ab, Cry1AC, Bt 11, Bt 176	PCR	$25/1000 seeds	Qualitatively detects 1 out of 1000 seeds, Quantitatively detects .01% GM presence	3 Days
RR, Liberty Link	Herbicide Bioassay	$25/1200 seeds	Depends upon minimum herbicide tolerance requirements	7 Days
Mon 810, 176, CBH351 (Cry9c)	ELISA Microtiter Plate	$65-$70/90 seeds	Cry9c, detection .04% and above, Mon810,176, .15% and above	9 Days
PAT/pat protein	ELISA Microtiter Plate	$195.00	Detection, .2%	2.5 Hours
Cry9C	ELISA Microtiter Plate	$16.00	Detection, .01%	3 Hours
CP4/EPSPS	ELISA Lateral Flow	$3.50	Detection, .5%	5-10 minutes
Mon 810, Bt11	ELISA Lateral Flow	$3.50	Detection, 1%	5-10 Minutes
Cry9C	ELISA Lateral Flow	$3.50	Detection, .125%	5-10 minutes
Soybean				
35S, NOS, RR	PCR	$25/1000 seeds	Qualitatively detects 1 out of 1000 seeds Quantitatively detects .01% GM presence	3 Days
RR, Liberty Link	Herbicide Bioassay	$18,$30,$50 (400,1200, 2000 seeds)	Depends upon minimum herbicide tolerance requirements	7 Days
CP4/EPSPS	ELISA Lateral Flow	$3.50	Detection, .1%	5-10 minutes

Source: Mid-West Seed Services, Inc., and EnviroLogix Inc.

GM Testing

GM testing is performed through detection of novel DNA or novel protein that modifies the grain or oilseed. Available tests include herbicide tolerance bioassay, Immuno assay encompassing the strip test and ELISA, and PCR. GM testing provides assurances to domestic end-users and importers as to the presence or absence of GM content and facilitates marketing between supply chain participants.

The designation of a testing methodology depends upon the number of transformation events that have to be detected and the preference for qualitative or quantitative results; for example, corn has 16 transformation events that have been granted environmental, feed, and food release in the United States while soybeans have 11, one of which is available commercially. This confers that divergent testing methodologies will be employed based on the number of transformation events, and ultimately those not approved for importation (Bullock, Desquibet, and Nitsi).

Protein Tests

Immuno Assay. The immuno assay test detects proteins created or expressed by the modified gene by locating the antibodies that attach to each respective protein. Immuno assay manifests itself through two types of tests including the strip test and the ELISA test.

Strip Test. Strip tests are rapid, accurate, cost-effective, and can be utilized in qualitatively assigning a "yes-no" response. It is the cheapest and easiest method of qualitative testing available and indicates a positive or a negative depending upon the pre-set level of novel protein. The process involves a ground sample, insertion into a tube, and a color change for positive or negative (Stave and Durandetta). Several companies market strip tests including EnviroLogix, Strategic Diagnostics, Inc. (SDI), Neogen Corporation, etc.

To accurately evaluate and assess testing kit performance, USDA-GIPSA (2002c) provides test kit performance verification via Directive 9181.2 to detect the presence of biotechnology events in grains and oilseeds and to assign a qualitative measurement. Concurrent with approval, manufacturers are successively listed on GIPSA's website along with the event/protein analyte, test sensitivity, and test format characteristics intrinsic to each approved test kit. Although test kit approval does not establish appropriate criterion for official use, it aids in facilitating market transactions between supply chain participants who are ascertaining product information to comply with market demands. The total cost for a strip test depends upon the desired event detection, but is approximately \$3.50 plus labor; for example, the total cost for detection of glyphosate-resistant soybeans is \$6.00, assuming \$3.50 for the test kit and 10 minutes labor at \$15.00 per hour (Bullock, Desquibet, and Nitsi).

ELISA (Enzyme Linked Immunosorbant Assay). The ELISA test is a laboratory test that quantifies GM content of a sample for a given transformation event. ELISA testing can be applied to raw agricultural products or slightly processed products to reveal a quantitative approximation of novel protein content (Bullock, Desquibet, and Nitsi). Novel protein percentage is determined through the examination of various hues with a plate reader that analyzes specific antibody reactions and indicates the concentration of the proteins that are created in conjunction with the genetic event (Strategic Diagnostics, Inc. 2003). Several laboratories offer ELISA tests, and both EnviroLogix and Agdia Inc. provide Bt corn testing, although no ELISA test currently exists for detecting herbicide tolerant varieties in corn. Both immuno assay tests can only be utilized to detect one event; consequently, several tests may be needed to test for exporter restrictions on several events; however, their simplicity and low cost make them ideal candidates for grain elevator or processing plant utilization (Bullock, Desquibet, and Nitsi).

DNA Grain Tests

PCR (Polymerase Chain Reaction). The PCR test is a laboratory test used to detect modified DNA by selectively multiplying targeted sections of a DNA molecule, identifying the novel DNA, and magnifying it over 1 million times. PCR testing can be applied to raw materials, processed materials, and mixed products; however, its susceptibly to contaminants or DNA degradation requires testing to be performed under rigorous laboratory conditions with appropriate controls. Several organizations have combated these shortcomings by modifying PCR tests to extend novel DNA detection to processed foods including Cepheid and Qualicon, Genetic ID, and LawLabs (Shoemaker et al.).

PCR testing can be measured both quantitatively and qualitatively depending upon the desired sensitivity. The quantitative PCR test uses a DNA probe to produce a fluorescent signal, which allows the progress of the PCR reaction to be monitored to accurately assign a reliable GM detection rate within 0.1%. A qualitative test allows even more sensitive results, which can detect traces of target DNA albeit results are reported as detected or not detected (Bullock, Desquibet, and Nitsi).

Synchronous Testing. Multiple events can be tested for simultaneously through the use of several primers, small DNA molecules whose sequence corresponds to DNA sequences present in GM commodities. Primers corresponding to DNA sequences present in many GMOs can be used to detect multiple GMOs, but does not state the modification type, whereas a primer corresponding to a DNA sequence of a given event allows us to recognize an unequivocal determination or one individual transformation, but requires several primers to recognize all transformations (Bullock, Desquibet, and Nitsi). Importer event restrictions require individual quantification of GM transformations; for example, 12 out of 16 events approved in the United States are not approved for import in the EU, while 8 out of 16 events are not approved in Japan. Consequently, a qualitative test adding $75 per event is needed to ascertain conformance to importer specifications, which amounts to $600 and $900 for Japan and the EU, respectively (Central-Hanse Analytical Laboratory, LLC). Since PCR is not readily adaptable for rapid onsite testing, it is better suited for laboratory examinations and export certifications where a large sample size exists (Shoemaker et al.).

Related Studies

Other logistical studies related to quality improvement include Porter and Rayners' process costing model and loss function, which utilizes an advanced TQM method for costing quality and quality improvements throughout the entire system and incorporates plant, facility, and training investment costs. Feigenbaums' PAF model (prevention, appraisal, and failure cost) is utilized in identifying quality costs, which include prevention costs (costs of actions to prevent, investigate, or reduce non-conformity), appraisal costs (costs of evaluation quality accomplishment), and failure costs (non-conformity costs endogenous and exogenous to the firm).

Porteus considers setup cost, rework, and investment requirements inherent to increasing quality and reducing setup costs on economic order quantities. The study indicates that increased logistical costs associated with increased quality uncertainty are borne by system participants. Variation of product quality (inconsistency) is a major factor in determining customer perception of poor quality (Ross) and variation in product quality (inconsistency) is a major factor in the rejection of parts and that the best way to control quality is through minimizing deviations from a target (increasing conformity) (Roy). The magnitude of non-conformance loss is dependent on the manufacturing process, target value, cost or rework, scrap, and warranty.

The Taguchi Loss Function measures deviations from ideal values and, thus, total losses imparted to the system from the time a product is shipped until it reaches the customer. The Taguchi Loss Function places more emphasis on customer satisfaction than other loss functions, which are focused on producers. Important assumptions of the Taguchi Loss Function including the following: 1) the quality loss function is a continuous function and measures target value deviations; 2) quality loss is essentially a product performance characteristic minimized by devising quality into the product; 3) quality loss is a result of customer dissatisfaction and should be measured system-wide; and 4) quality loss is a social and financial loss. The nominal value estimation of the Taguchi Loss Function can be modeled as follows: $L(X) = k(X-T)^2$, where $L(X)$ is the quality loss, k is the adjustment factor, X is the observed parameter, and T is the parameter target value. An alternative formulation when higher values are better is $L(X) = k/X^2$ and for lower values is $L(X) = k * X^2$.

Tolerances

Statistical tolerancing is one approach for quantifying a threshold for a specified tolerance. High/low specification provides a range about nominal values, which in the case of transgenic testing will only provide an upper limit. Statistical tolerance assigns a probability of a mechanism to be nonzero, which allows component tolerances to be defined as probability distributions (Evans, 1974, 1975). Components may include the presence of a transgenic attribute, which is important for end-users, processors, producers, and input suppliers. A trial and error approach is plausible for discerning between GM and Non-GM product. The trial and error approach consists of the following: postulate tolerances for testing, perform an analysis to evaluate postulated tolerances, reiterate results until satisfied, evaluate tradeoffs of varying tolerance levels (i.e., out of contract), cost/benefit analysis, and finally the assignment of a probability of meeting a contract specification (Evans, 1974, 1975). Tolerance can be disaggregated into a regulatory and a commercial tolerance, which comprise the conformance guidelines suppliers are subjected to.

Commercial

A commercial tolerance is a firm-imposed tolerance designated to meet conformance standards for an individual firm. Commercial tolerances evolve contingent on the adoption of a regulatory tolerance and its specified threshold. Currently, corn and soybeans comprise the majority of discussion as to commercial tolerance discrepancy, but in light of the continual inception of new transgenic varieties, commencement of additional deliberation will be imperative. Although not exhaustive, motivation for establishing thresholds can be attributed to disparity in consumer demands, product differentiation, market share, public perception and/or consumer awareness. Inevitably as biotech products are developed and evolve, commercial tolerances will be adopted concurrently with regulatory mandates in an effort to minimize biotech acceptance cost.

THEORETICAL MODEL

Tolerances play a pivotal role in the determination of an optimal testing strategy to mitigate the risk of non-conformance. Other studies have identified tolerance allocation procedures designed to minimize supplier cost and quality loss. The bulk of the research is dedicated to manufacturing processes and the concurrent design of dimensional components to adhere to an overall assembly tolerance. Tolerance, as defined in this context, refers to grain and its maximum allowable contrasting factor(s) such as percentage GM. The definition of tolerance necessitates identifying the factors that comprise its inherent risk.

Tolerance Defined

Wu, Elmaraghy, and Elmaraghy define tolerance as the maximum deviation from a nominal specification within which the component is still acceptable for its intended purpose. Irianto refers to tolerance as a given parameter known as a specification limit. While there are varying definitions of tolerance, a consensus among scholars identifies a relationship between tolerance and cost. Tolerance defines the maximum, minimum, or range of desired target values, while costs include testing and market loss resulting from non-conformance. Various mathematical functions have been proposed in the literature to fit manufacturing cost-tolerance field data including Sutherland, reciprocal, reciprocal-square, exponential, and Michael-Siddall functions (Wu, Elmaraghy, and Elmaraghy).

The general relationship exists, that if tolerance is tightened (loosened) it leads to higher (lower) incurred costs because effort is altered to meet specifications (Irianto; Jeang; Wu, Chen, and Tang). Tolerances and the specification of an optimal tolerance will ultimately vary depending upon "out of contract costs," also known as the alternative market discount. Generally, the higher (lower) the discount for non-conforming grain, the tighter (looser) the tolerance specification. This implies that as non-conformance costs escalate, a more rigorous approach to sampling, testing, and certifying will be adopted. Concurrently, loss associated with tolerance specification should be evaluated in conjunction with testing costs to arrive at an optimal tolerance.

Several authors examine tolerance assignment via experimental design techniques utilizing the Taguchi Loss Function and the concurrent minimization of total cost incorporating manufacturing cost and quality loss costs to determine an optimal tolerance. Other authors attempt to determine least-cost tolerance assignment via computer-aided controlled tolerancing systems, orthogonal array assignment, statistical tolerancing methods, simulation, etc. Pertinent studies will be presented in following sections and explored in detail to determine optimal tolerances.

Tolerance Analysis Models

Wu, Elmaraghy, and Elmaraghy examine numerous dimensional design tolerance synthesis and analysis models to effectively compare tolerance analysis and tolerance allocation methods. Tolerance allocation models are designed to determine what tolerances should be designated along the supply chain in order to adhere to a specified assembly tolerance (i.e., importer tolerance), whereby tolerance analysis models predict assembly tolerances approximating actuality in an attempt to reduce rejects. Each has a significant bearing on optimal tolerance assignment since grain will inevitably be tested throughout many locations along the supply chain to meet an overall tolerance, while mitigating the potential for a rejected grain lot.

The cost-tolerance function aims at optimizing component tolerances, while adhering to an assembly tolerance to minimize an overall assembly cost function. Wu, Elmaraghy, and Elmaraghy examine five functions including Sutherland, reciprocal square, reciprocal, exponential, and Michael-Siddall. The criterion for evaluation utilizes the non-linear least square method that is fit to each function, whereby the value of the error is minimized and indexed to compare competing functions and indicate goodness of fit and parameter estimations.

Wu, Elmaraghy, and Elmaraghy discuss several tolerance allocation methods that have been adopted to minimize total manufacturing costs. Results indicate that the Lagrange multiplier and geometric programming cost-tolerance allocation methods achieve the lowest average cost. However, the Lagrange multiplier method does not have the capability to handle the Michael-Siddall function, while the geometric programming method only has the capability to handle the exponential function. Despite these limitations, true optimum solutions can be obtained with simplicity, reliability, and little computational effort. The remaining cost-tolerance allocation methods have the capability to handle all above mentioned cost-tolerance functions, but remain inferior with respect to average cost, computational effort, simplicity, and/or reliability when compared to the Lagrange multiplier and geometric programming methods.

Pertinent studies in this area also include a methodology to solve a tolerance allocation-process selection problem simultaneously (Nagarwala, Pulat, and Raman) and an orthogonal-based algorithm for least cost tolerance allocation and optimal process selection (Gadallah and Elmaraghy).

Quality Loss and Tolerances

Quality loss is associated with deviation from the target or goal value of a dimension. Several authors regard quality loss as a customer loss when the product or parts do not conform to expectations; consequently, customer loss becomes equivalent to a realized quality loss, manifesting itself through warranty cost, handling cost, customer dissatisfaction, and/or the loss of goodwill (Irianto). Hence, the designation of an optimal tolerance must evaluate the cost of quality loss and testing cost simultaneously to effectively minimize total cost.

Numerous studies identify loss functions that quantify cost of quality loss; however, the Taguchi method has proved to be superior due to its simplicity and good results (D'Errico and Zaino, Jr.). Historically, a Lower Allowable Limit (LAL) and an Upper Allowable Limit (UAL) represented the acceptable limits of a design parameter whereby no societal loss was assumed to occur (Roy). The goalpost syndrome refers to where no loss occurs within the LAL and UAL region, but where a loss is incurred in the form of an expense whenever the parameter deviates from that range (Ross). The Taguchi Loss Function is generally represented with the following notation:

$$L(y) = k(y - m)^2$$

Where:

$L(y)$ is the quality loss function,
k is adjustment factor (constant),
y is single product quality characteristic, and
m is desired target value.

The aforementioned representation of the loss function assumes that a nominal product quality characteristic is desired, so that if any positive or negative deviation from the nominal occurs, it will be accompanied by a quality loss cost (Irianto). The loss function can also be applied in situations in which smaller-is-better and larger-is-better and is modeled with the notation, $L(y)=k(y^2)$ and $L(y)=k(1/y^2)$, respectively.

Irianto explores the Taguchi Loss Function, a quadratic loss function that approximates the balance between customers' loss from performance deviation and producers' effort for performance improvement. In this study, inspection and correction policies are evaluated utilizing two differing policies that represent synchronous and non-synchronous rectification of non-conforming products. The summation of inspection, correction, and hidden quality loss cost, defined via the Taguchi Loss Function, allows the most economical tolerance to be attained, while aiding in policy selection.

In determining optimal tolerance, Irianto assumed customer dissatisfaction when product quality characteristics deviated from the nominal target value; hence, the loss function is defined as follows: $L(y)=k(y-m)^2$ where k is a constant estimated from claim costs (C_O) and target value (Δ_O) as C_0/D^2_0, and other variables are as previously defined. The second cost component in determining an optimal tolerance stems from inspection of all products and correction of non-conforming products. The total cost can be represented as $TC_D= L_D+C_D$ where L_D is the quality loss and C_D is the total measurable cost; consequently, the optimal tolerance (D^*) minimizes TC_D. Irianto illustrates optimal tolerancing via a numerical example where inspection is assumed to be perfect, and the process follows a normal distribution function. This approach is directly applicable to GM grain and the concurrent determination of an optimal tolerance since quality loss is realized in the form of an alternative market cost when the grain lot is non-conforming, and a measurable testing cost is incurred to meet tolerance specifications.

Wu, Chen, and Tang solve the problem of tolerance assignment via a single optimization process to minimize total cost, which includes manufacturing cost and quality loss of assemblies. Conventional tolerance design lacks a quality factor consideration, but Taguchi's approach ignores variations in manufacturing cost based on tolerances assigned. Thus, a very tight tolerance causes a correspondingly large total cost due to manufacturing, whereas a relaxed tolerance causes a large total cost due to quality loss. Hence, Wu, Chen, and Tang propose a new method whereby quality loss and manufacturing cost are taken into account simultaneously to define an optimal tolerance for both symmetric and asymmetric loss functions.

A cost-tolerance curve is determined from the connection between the manufacturing cost of a component and the accuracy level desired. Generally, the manufacturing cost increases as the permissible tolerance decreases and vice versa. Multiple component assemblies require aggregated manufacturing costs of individual components and can be represented as $M = \sum C_i(t_i)$ where M is manufacturing cost, C_i is each individual component, and t_i is the individual component cost. The assembly tolerance is a function of resultant dimensions; therefore, proper tolerance assignments among resultant dimensions assure adherence to the overall assembly tolerance. GM commodities may be represented through the use of resultant dimensions, since movement of GM grain through the supply chain necessitates repeated testing at different points to assure conformance. Wu, Chen, and Tangs' interpretation of quality loss is tantamount to that of Irianto, where $L(y)=K(y-m)^2$ and $K=A/\Delta^2$ is determined by estimating an overall loss of A when a product deviates Δ from the target value.

The symmetric loss function considers positive and negative deviations from a target value to have equal bearing on quality loss. In order to define an optimal tolerance, the effects of manufacturing cost and quality loss on tolerance assignment must be translated into the same coordinates via a monetary index or resultant tolerance. The following integration,

$L = \int_{-\infty}^{\infty} f(y)K(y-m)^2 dy = Kz^2$, evaluates average loss L of a batch product, where f is the density function, y is the resultant dimension, z is the standard deviation of the products' dimension, and m is the target value. It can be rewritten as $L=KA_r^2$ where A is a constant. Since production data is only available for individual components, the manufacturing cost of the assembly is assumed to be equal to the manufacturing cost of the component and the resulting tolerance to that of the component tolerance. When quality loss and manufacturing cost are plotted, a total cost curve can be graphically obtained, which is concave; therefore, the minimum of the curve is the optimal resultant tolerance t^*.

Krishnaswami and Mayne employ a procedure for optimizing the allocation of tolerances while considering manufacturing cost and product quality in a constrained optimization framework. The Taguchi Loss Function is specified as $L=A/D^2*(y-m)^2$, where A is the cost of repair when dimensions are nonconforming, m is the dimension target value, D is the dimension tolerance, and y is a particular dimensional value. The loss L describes the cost of a non-conforming dimension when the target value is not realized; however, full loss does not occur until the assembly tolerance is violated. If the functional dimension is assumed to follow a normal distribution with its mean at the target value, quality loss can be rewritten in terms of the standard deviation of the functional dimension as $L=A/D^2*s^2$. Manufacturing costs were obtained via the exponential cost-tolerance function utilizing actual cost data for varying tolerance specifications. Then, an optimal tolerance allocation procedure utilizing non-linear programming techniques is employed to minimize the total cost.

Similarly, Taguchi examines loss function with smaller-is-better characteristics, where the target value is zero, and no negative values are assumed. The loss function can be represented as follows, $L=(A_O/D_O^2)*s^2$, where D_O is the consumer upper tolerance limit, A_O is the loss imparted to society when the upper tolerance limit is exceeded, and s^2 is the variance. The variance for GM lot concentration from zero can be calculated through averaging variance for all bushels within the delivered lot (Taguchi).

The objective function is to minimize total cost composed of additional system testing costs (all supply chain points) + quality loss $((A_O/D_O^2)*s^2)$ of non-conformance to a target value of zero GM lot concentration (Taguchi). The optimum testing and tolerance strategy can be derived from the preceding enumeration and ultimately depends on the desired tolerance specification. Comparative statistics were conducted on the critical parameter A_O, which represents the loss imparted to society. Results concluded that for increasing (decreasing) values of A, the resulting optimal tolerances were tightened (loosened) to avert nonconformance (Krishnaswami and Mayne). This study provides evidence that as “out of contract costs” increase, for example, in the case of GM grain, tolerances will be correspondingly tightened and vice versa. This presents several implications for testing strategies across the supply chain and or the testing methodologies that will be utilized.

EMPIRICAL MODEL

The model of a cost function utilizing *Risk Optimizer* was developed to minimize disutility of additional system costs, which are comprised of testing cost, quality loss at each marketing location, and a risk premium required for grain handlers to undertake a dual marketing system versus a Non-GM system. Testing costs are commensurate with respect to application point, intensity, and applied tolerance. Quality loss is incurred at change of ownership points and is calculated based on the deviation from the target value for GM lot concentration, which is assumed to be zero. Model assumptions include specified GM/Non-GM adoption, probability distributions for adventitious commingling, variety declaration, and binomial distributions to explain the probability of acceptance given varying tolerances and the concentration in the lot. Tests can be applied at various grain marketing locations when received and loaded to identify Non-GM grain flows that exceed GM tolerances. The lots identified as exceeding tolerances are diverted to GM flows and subjected to quality loss. Non-GM and GM flows are tracked throughout the system to identify the quantity of Non-GM grain delivered and the amount of GM grain diverted.

A grain flow diagram and a general description of model components are presented in the first section. Figure 1 provides an illustration of grain flows in a dual marketing system. The following sections examine the mathematical model description, model elements, parameter specifications, data sources, and simulation procedures.

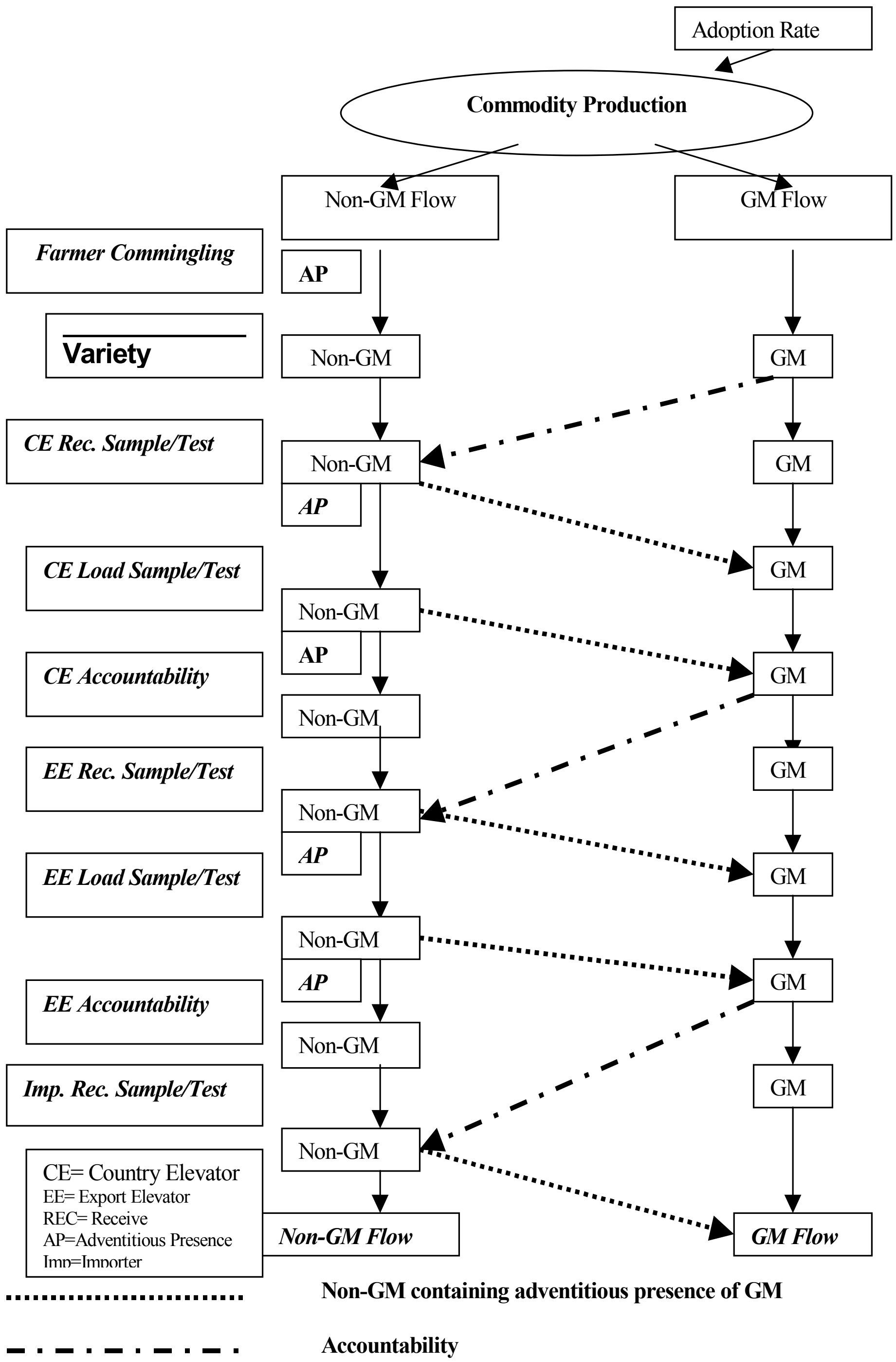

Figure 1. Grain Handling Subject to Adventitious Presence.

Grain flows are tracked throughout the system as Non-GM clean, Non-GM commingled, and GM. Non-GM grain is subjected to adventitious commingling risk from handling and transportation functions inherent in the system and farmer variety declaration. Non-GM lots exceeding tolerances are diverted to the GM flow at the marketing chain point when they are identified and subjected to quality loss. The distribution of grain flows at the importer or domestic end-user determines the allocation of additional system costs for Non-GM grain.

Model Overview

The model simultaneously determines the optimal testing strategy (application, intensity, and tolerance) to employ for a dual marketing system encompassing Non-GM and GM grain flows. Incentives to adopt in a dual marketing system are provided to market chain participants from a risk premium, which is specified as p = EV_{NGM} – CE, where p is the value of the risk premium, EV_{NGM} is the expected costs for a dual system, and CE is the certainty equivalent of the utility of additional costs for a dual marketing system. The premium p represents the point at which decision makers would be indifferent between a Non-GM and dual system.

Testing locations in the grain marketing chain include country elevator receiving and loading, export elevator receiving and loading, and either importer or domestic end-user receiving. Tests can be applied at any of these functions with varying discrete intensities (i.e., 1:1 to 1:5) and tolerances (i.e., .04% to 5%). Strip tests are utilized at country and export elevators to provide low cost, accurate, and timely results while PCR tests are employed at the importer and domestic end-user to reflect industry practices (EnviroLogix Inc.). Tests are required on every lot at the importer and domestic end-user at a predetermined tolerance concurrent with industry procedures.

Mathematical Model Description

Utility Specification

The model uses stochastic optimization of a grain marketing chain that utilizes an objective function to quantify a risk premium. Expo-Power Utility, a flexible form for absolute and relative risk aversion, was developed initially by Saha and previously used by Serrao and Coelho to determine optimal cropland allocation and risk premiums for crop insurance programs. The objective function contains a von-Neumann-Morgenstern type utility function, with decreasing absolute risk aversion and increasing relative risk aversion. The model chooses the optimal testing strategy (where to test, test intensity, and test tolerance) that maximizes portfolio utility (which is equivalent to minimizing portfolio disutility) by minimizing additional system costs for a supply chain handling a portfolio of segregations representing two states of nature (Non-GM and GM). The portfolio utility is comprised of the weighted disutility of additional system costs (testing and quality loss) for handling both states of nature. The objective function can be expressed by the following equation:

$$MaxU = Min(C) = \sum_{i=1}^{2} \delta_i (\lambda - e^{(-\phi C_i^{\eta})})$$

$$\text{s.a. } \mathbf{X_j} \in \mathbf{K_j}$$

Where:

- δ_i is the proportion of flows devoted to each state of nature (i=1-2),
- e is the base of the natural logarithm,
- λ is a parameter that determines positiveness of the utility function,
- ϕ and η are parameters which affect the absolute and relative risk aversion of the utility function,
- $\boldsymbol{C_i}$ is the additional system costs associated with each state of nature (i=1,2), as previously defined,
- $\boldsymbol{X_j}$ is the decision variable vectors of the model,
- $\boldsymbol{K_j}$ is the opportunity set of model,
- i is states of nature Non-GM=1 and GM=2, and
- j represents test application T_μ, and sampling intensity S_μ, at location μ and tolerance i.

Parameters of the utility function are λ, ϕ, and η. A value of $\lambda = 2$ corroborates with Saha and guarantees positiveness of the utility function. Increasing the risk parameter ϕ while holding η constant results in an essentially linear effect on the absolute risk aversion. Hence, the variation of parameter ϕ amplifies the risk aversion coefficient without altering solutions. However, the parameter η exhibits a non-linear behavior relative to the absolute risk aversion coefficient when ϕ is held constant. Since the objective function is more sensitive to η versus ϕ, the parameter ϕ is fixed at 0.01 and η is allowed to vary from 0.4 to 0.9. Thus, λ and ϕ are fixed and sensitivities are conducted about η.

Additional System Cost

The additional system costs of a dual marketing system are composed of testing, risk premium, and quality loss costs. Testing costs are summed across grain marketing points utilizing strip test technology at all intermediate points (i.e., country and export elevator) and PCR test technology at the importer or domestic end-user. Testing costs are incurred at grain marketing locations. The optimal testing strategy is determined with respect to testing intensity and tolerance. Strip tests are utilized at receiving and loading functions of the country and export elevator locations while PCR tests are used at the domestic end-user and importer locations (Table 3).

Additional system costs arising from testing are defined as:

$$C_{NGM} = \sum_{\mu=i=1}^{n} T_\mu * TC_{\mu i} * S_{\mu i} * V_{NGM\,\mu}$$

$$C_{GM} = 0$$

Where:

C_{NGM} is the additional testing cost accrued to maintain GM separation for Non-GM shipments,

C_{GM} is the additional cost for GM bushels,

μ is the location within the system where tests can be applied (country elevator receiving, country elevator loading, export elevator receiving, export elevator loading, importer receiving, domestic user receiving),

T_{μ} is a binary choice variable reflecting whether tests are applied at location μ,

$TC_{\mu i}$ is the cost of individual test for location μ and tolerance i,

$S_{\mu i}$ is the sampling intensity (number of samples per lot) at location μ and tolerance i, and

$V_{NGM\mu}$ is the volume (number of lots) of Non-GM handled at location μ.

Table 3. GM Testing Tolerances, Costs, and Accuracies

		Strip Tests	
Tolerance (%)	**Accuracy(%)**	**Required Seeds**	**Cost per Test ($)**
0.04	95	8000	28.0
0.05	95	6000	21.0
0.075	95	4000	14.0
0.10	95	3000	10.5
0.25	95	2000	10.5
0.50	99	1000	3.5
0.75	99	1000	3.5
1.00	99	1000	3.5
2.00	99	400	3.5
3.00	99	400	3.5
4.00	99	125	3.5
5.00	99	125	3.5
		PCR Tests	
0.01	99	10000	275
0.05	99	10000	275
0.075	99	10000	275
0.10	99	7500	262
0.25	99	5000	250
0.50	99	2500	250
0.75	99	2500	250
1.00	99	2500	250
2.00	99	2500	250
3.00	99	2500	250
4.00	99	2500	250
5.00	99	2500	250

Source: Strip – Strategic Diagnostics Inc. (2003), PCR – Mid-West Seed Services, Inc.

Risk Premium

The risk premium utilizes λ, ϕ, and η and portfolio utility to define the additional revenue required for decision makers to be indifferent between a Non-GM versus a dual marketing system. The risk premium compensates the handler/shipper for potential risks emanating from detection of GM content in a Non-GM flow, which is subject to quality loss. The risk premium is derived from the expected value of the system as follows:

$$\pi = EV_{NGM} - \hat{C}_{GM/NGM}$$

Where:

$$U(\hat{C})_{GM/NGM} = EU(C)_{GM/NGM} = E(\sum_{i=1}^{2} \delta_i (\lambda - e^{(-\phi \hat{C}_i^{\eta})})$$

π is the risk premium for the dual system, EV_{NGM} is the expected additional cost of a Non-GM system assumed to be zero, $\hat{C}$ is the certainty equivalent of additional system costs for a dual system, and other parameters are as previously defined.

Quality Loss

Quality loss cost is incurred at change of ownership points when grain is delivered. In the case of an integrated firm, quality loss only occurs at the final destination point (importer or domestic end-user). A Taguchi Loss Function with smaller-is-better characteristics is utilized to calculate quality loss *imparted to society*. The function does not take on negative values and has a target value of zero (Taguchi). The loss is comprised of costs incurred by the handler/shipper and the end-user. The handler/shipper is exposed to rejection cost, loss of future business, etc., at the end-user while the end-user is exposed to grain quality risks (Ross). Thus, the handler/shipper utilizes testing to reduce quality loss, and the end-user specifies a tolerance to assess quality deviations. Quality deviations from the target value of zero represent an implicit cost to the system; thus, shipments containing minimal GM content incur quality losses. Shipments containing lower (higher) lot concentrations incur smaller (larger) quality loss (Figure 2).

Additional system costs attributable to quality loss are defined as follows:

$$L = \frac{A_O}{\Delta_{O^2}} \cdot \sigma^2$$

Where:

L is the Taguchi Loss Function with smaller-is-better characteristics,
Δ_o is the imposed buyer upper tolerance limit,
A_O is the loss imparted to society when the upper tolerance limit is exceeded,
σ^2 is the average lot variance for the distribution of GM lot concentration at change of ownership points from a target value of zero.

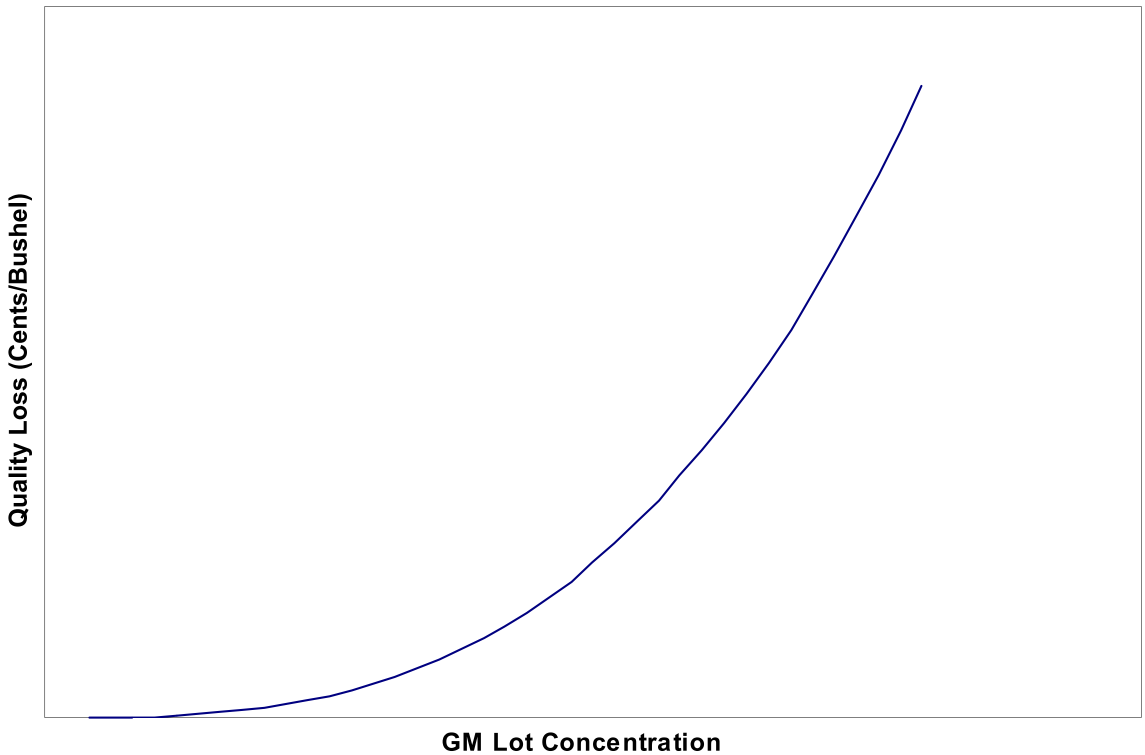

Figure 2. Effect of GM Lot Concentration on Quality Loss

The summation of these components of additional system costs is represented as follows:

$$C_{NGM} = \sum_{\mu=i=1}^{n} (T_{\mu} * TC_{\mu i} * S_{\mu i} * V_{NGM\mu}) + (\frac{A_o}{\Delta_o} * \sigma^2)$$

Where C_{NGM} is the additional testing and quality loss cost added to Non-GM shipments to maintain GM separation, and other parameters are as previously defined.

Total Cost

The risk premium, testing cost, and quality loss constitute the total additional cost required to operate a dual marketing system over a Non-GM system. Total economic costs include a direct cost and an indirect cost component. The direct component accounts for testing costs along the supply chain, and the risk premium required to induce the handler/shipper to handle both GM and Non-GM. The indirect component accounts for quality loss incurred at any deviation above the target value of zero. The aggregation of both components equates a total economic cost that the organization can expect to incur through cash outlay, customer dissatisfaction, loss of future business, goodwill, etc. (Ross).

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Detailed Description of Model

This section provides a more detailed description of the model. The flow of grain and how additional system costs are calculated is included in the following sections.

Country Elevator

Total production is partitioned into a Non-GM and GM grain stream. Adventitious Presence (AP) occurs at the farm level due to inadequate sanitation for production and handling equipment, cross-pollination, and logistical risks. Non-GM and GM lots are originated at the country elevator with and without farmer variety declaration. A binomial distribution is utilized to confer operating characteristic (OC) curves that identify the probability of accepting a Non-GM lot given its underlying lot concentration and a specified tolerance. Sampling parameters within the Non-GM stream are population size, sample size, and defective units. The two former parameters are based on lot specification and sampling intensity, respectively, while the latter is calculated from the binomial distribution.

The model chooses whether to apply a test at each grain marketing point and its accompanying intensity and tolerance. If a test is applied, samples are drawn, identified, and diverted accordingly. Non-GM and GM flows are segregated at the commencement of testing. Identified GM flows are diverted to the GM grain stream. Non-GM flows are divided into Non-GM clean and Non-GM AP by accounting for sampled and rejected, un-sampled and rejected, and misidentified lots. Sampled and rejected lots are lots that have been sampled and identified as GM. Un-sampled and rejected lots are lots that have not been sampled, but are equally represented by a sampled lot when testing intensities are less than 1:1. Misidentified lots are sampled and rejected lots that contain a Type I error due to test accuracy less than 100% (Mendenhall and Sincich). The proportion of GM and Non-GM grain is recorded as country elevator stored percentage.

An estimate of adventitious commingling potential for a dual system is taken from the recent Starlink corn incident. Aventis submitted adventitious commingling rates for 33 off-farm elevators in seven states that indicated StarLink corn was present at concentrations ranging from 0.25% to 62.5% with an average of 3.5%. Environmental Protection Agency (EPA) concurred that the degree of mixing will vary from lot to lot depending upon delivered StarLink percentages, size of storage facilities, and the number of elevations. Jenkyn corroborates these findings through the investigation of flow patterns within storage facilities indicating grain cohesiveness, internal friction, and outlet eccentricity affects adventitious commingling rates. EPA estimated an upper bound for StarLink adventitious commingling potential at 1.2% and 1.5% for 1999 and 2000, respectively. This represents a adventitious commingling rate three to four times the overall percentage acreage planted to StarLink of .32% and .43% in 1999 and 2000, respectively (EPA). Hence, a conservative adventitious commingling rate applied to grain received at the country elevator is three times the percentage of unidentified GM lots plus adventitious commingling risk for handling (see Table 4).

Table 4. Base Case Adventitious Commingling Distributions

Location	Distribution	Minimum	Most Likely	Maximum
Grower Risk	Triangular	0.01	0.025	0.05
Country Elevator	Triangular			
Receiving		0.001+3*GM	0.01+3*GM	0.02+3*GM
Loading		.001	.01	.025
Export Elevator	Triangular			
Receiving		0.001	0.01	0.025
Loading		0.001	0.01	0.025

Source: Hurburgh (Grower Risk), Casada, Ingles, and Maghirang (Shipping/Handling Risk), Environmental Protection Agency (Unidentified GM at First Delivery) Note: GM = % GM unidentified.

Export Elevator

Grain shipped to export is subjected to adventitious commingling risk from shipping and country elevator export accountability. The binomial distribution is similarly applied, sampling and testing is performed, and flows are diverted and apportioned accordingly. The proportion of GM and Non-GM grain is recorded as export elevator received percentage.

Grain loaded at export is exposed to adventitious commingling risk from elevating grain to appropriate shipping bins. The binomial distribution is applied, sampling and testing is conducted, and flows are diverted and apportioned accordingly. The proportion of GM and Non-GM grain is recorded as export elevator loaded percentage.

Importer Receiving

Non-GM shipments arriving from export elevator origination points are subject to adventitious commingling risk from export shipping and export elevator accountability. Grain received at the importer represents a change of ownership point; consequently, quality loss is calculated based on the delivered grain lot. A tolerance range is specified from 0% to 100%, and the probability of accepting the lot is calculated using the aforementioned binomial distribution. The relative percentages from 0% to 100% are multiplied by the amount of Non-GM grain to obtain the number of observations in each tolerance range. The average between successive tolerances is calculated, squared, and multiplied by the change in successive observations to configure individual tolerance variances. Subsequently, tolerance variances are summed to arrive at average lot variance for the distribution of GM lot concentration for the importer. The resulting variance, upper tolerance limit, imparted loss, and Non-GM quantity is utilized to calculate quality loss from exceeding the target value of 0%.

Sampling and testing identify GM lots exceeding tolerance to be diverted and apportion Non-GM into Non-GM Clean and Non-GM AP. Buyer and seller risks are measured directly. The seller's risk is the probability of lot being rejected at the importer when it is in fact Non-

GM. Whereas the buyer's risk is the probability that an unsatisfactory lot (Non-GM AP) is not rejected at the importer (Winston). The proportion of GM and Non-GM grain is recorded as importer percentage and used to calculate costs for Non-GM bushels.

Domestic End-User

Grain shipped to the domestic end-user via the country elevator is subject to domestic shipping adventitious commingling risk and country elevator accountability. Additionally, quality loss and buyer/seller risk are calculated as aforementioned. The proportion of GM and Non-GM grain is recorded as domestic percentage and used to calculate costs for Non-GM bushels.

Detailed Description of Model Elements and Parameter Calculations

The following sections define distributions and parameters used in the model. Parameter calculations are described and distributions are specified. The model incorporates risk in several random variables. These include sampling risk at locations where sampling is conducted (number of samples identified); adventitious commingling risks at several locations (farm, country elevator, export elevator, and transportation equipment) due to inadequate cleaning, etc.; variety declaration; binomial; test accuracy and quality loss. Additional model elements examined include transportation modes and optimal testing parameters.

Sampling

Sampling for the detection of biotech grains introduces risk to exporters and importers alike. The inherent risk can be classified into three basic categories: (1) sampling, (2) sample preparation, and (3) analytical method. Sampling encompasses establishment of a quality level, protocol selection, sample size, and sampling tools. Sampling protocols are available to mitigate risks to buyers and sellers including single, double, and multiple sampling plans that incorporate AQL (Acceptable Quality Level) and LTPD (Lot Tolerance Percent Defective). Sellers select a quality level that they want to have accepted most of the time (e.g., 90% or 95%) called an AQL whereas buyers select a quality level that they want rejected the majority of the time (e.g., 90% or 95%) referred to as LTPD. The probability of rejection of a satisfactory batch whose quality actually equals the AQL is referred to as seller's risk whereas the probability of accepting a lot whose quality is unsatisfactory is referred to as buyer's risk.

In order to quantify seller and buyer's risk, the *Risk Hypergeometric* distribution utilizes lot size, sample size, and defectives concurrently. A more complex method is the double sampling plan, which entails defective ranges for accept or reject, and an intermediary range where the decision is indeterminate. In order to ascertain this indifference, a larger sample size is analyzed and if the sum of the total defectives is greater than the upper bound, the lot is rejected, otherwise it is accepted (Winston). A multiple qualitative sampling plan utilizes a specified number of independent samples to assign a positive or negative indicator. The maximum allotted positive results is determined to accept or reject the lot; hence, the higher the allotment for positives, the higher the probability of accepting the lot for any given percent concentration (USDA-GIPSA, 2000).

Adventitious Commingling Distributions

Adventitious commingling distributions used in the model utilize previous studies conducted by the EPA on StarLink corn on variety risk, and Hurburgh and Casada, Ingles, and Maghirang on handling risk. A *Risk Triangle* distribution was utilized to reflect the minimum, most likely, and maximum value. The distribution for farm level adventitious commingling was estimated from studies on grower risks inclusive of volunteers, pollen drift, and on-farm handling (Hurburgh; Thomas and Leeson; Hucl and Matus-Cadiz). Country elevator receiving adventitious commingling rate includes handling (Casada, Ingles, and Maghirang) and variety risk (EPA). Country elevator loading adventitious commingling rate includes shipping/handling risk (Casada, Ingles, and Maghirang). Export elevator receiving and loading adventitious commingling rates include handling and shipping/handling risk, respectively. The distributions are presented in Table 4.

Variety Declaration Distributions

Variety declaration indicates farmer, country elevator, and export elevator accountability when declaring grain shipments. The base case scenario assumes variety declaration at the farmer level is zero (i.e., no variety declaration). Variety declaration elsewhere assumes contractual relations and/or elevator-imposed mechanisms govern farmer deliveries. Variety declaration estimates were solicited in a survey of market participants knowledgeable on GM corn and soybean marketing (Wilson and Dahl, 2002). Results were used to derive a *Risk Triangle* distribution for variety declaration which represents the probability that farmers will tell the truth (i.e., accountability) when delivering Non-GM or GM grain. Table 5 summarizes variety declaration distributions.

Table 5. Variety Declaration Distributions

Location	Distribution	Minimum	Most Likely	Maximum
No Variety Declaration (Base Case)				
Farmer	NA	0	0	0
Country Elevator	Triangular	0.95	0.99	1
Export Elevator	Triangular	0.98	0.99	1
Variety Declaration				
Farmer	Triangular	0.8	0.95	1
Country Elevator	Triangular	0.95	0.99	1
Export Elevator	Triangular	0.98	0.99	1

Source: Wilson and Dahl, 2002.

Binomial Distribution

A binomial distribution is utilized to determine the probability of accepting various lot concentrations with specified tolerances. Tightening (loosening) tolerance decreases (increases) the probability of accepting a given lot concentration. The model utilizes the binomial distribution to simultaneously determine the optimal testing strategy (application, intensity, tolerance). It is specified as BINOMDIST (number_s, trials, probability_s, cumulative), where number_s is the number of successes (lot size * tolerance), trials is the lot size, probability_s is the underlying lot concentration, and cumulative is TRUE. Lot size is 1000, tolerance ranges from .04% to 5%, and lot concentration is defined as $\frac{NGM_{AP}}{NGM_{Total}}$ at the designated grain Fmarketing point. The model identifies the probability of rejecting a lot at each location depending upon incoming GM lot concentration in the Non-GM flow and the simulated tolerance at each location. The probability of rejecting a lot is defined as, $P_{REJECT} = 1\text{-}P_{ACCEPT}$, and potential grain rejection equals, $NGM_{AP}*P_{REJECT}$. The calculation, $NGM_{AP}*P_{REJECT}$ defines defective units in the *Risk Hypergeometric* distribution, which subsequently determines the amount of grain rejected and diverted within the Non-GM flow. Figure 3 illustrates computed Operating Characteristic (OC) curves using the normal approximation to the binomial. The probability curves depict the probability of acceptance given GM lot concentration and tolerance.

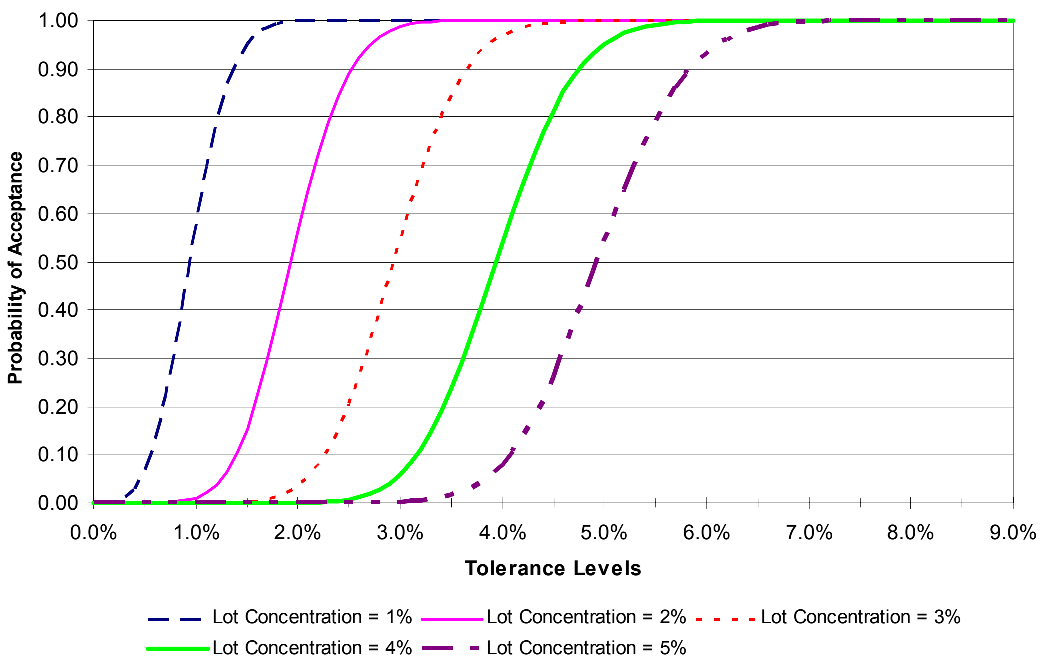

Figure 3. Operating Characteristic Curves

Test Accuracy

Through the optimal selection of a test tolerance, the model defines the corresponding test accuracy. Tolerance and its corresponding test accuracy are presented in Table 6.

Table 6. Base Case Test Tolerance/Accuracy

Test Tolerance (%)	**Accuracy (%)**	**Cost ($)**
	Strip Tests	
0.04	95	28.0
0.05	95	21.0
0.075	95	14.0
0.10	95	10.5
0.25	95	10.5
0.50	99	3.5
0.75	99	3.5
1.00	99	3.5
2.00	99	3.5
3.00	99	3.5
4.00	99	3.5
5.00	99	3.5
	PCR Tests	
0.04	99	275
0.05	99	275
0.075	99	275
0.10	99	262
0.25	99	250
0.50	99	250
0.75	99	250
1.00	99	250
2.00	99	250
3.00	99	250
4.00	99	250
5.00	99	250

Source: Strip – Strategic Diagnostics Inc. (2003), PCR – Mid-West Seed Services, Inc.

Quality Loss Distribution

Quality loss is the loss imparted to society when deviating from the designated target value of zero. The penalty, A_O for exceeding the upper GM tolerance limit is uniformly distributed with a range of 40-90 c/bu in the export market and 2-20 c/bu in the domestic market. Additional penalties at intermediate points may be incurred due to re-elevation charges or grain transfers among non-integrated firms. This penalty range identifies a best/worse case scenario through two cost components, discounted grain and logistical costs. Discounts for GM in Non-GM corn are historically 10% of the value, which is approximately 40 c/bu in the case of wheat. In addition, rejection may entail re-shipping grain to an alternative market, which is 50 c/bu in many geographic locations internationally. Ultimately, contract specifications govern the testing protocols and penalties sustained by the buyer and seller. Origin versus destination testing and external shipping bins provide flexibility to the shipper for re-routing of GM lots and minimizes out-of contract costs.

Transportation Modes

Transportation modes were designated for grain marketing locations and include truck, rail, and barge hold for country elevator receiving, country elevator loading/export elevator receiving, and export elevator loading/importer receiving, respectively. Sampling is conducted on the respective mode at each location and determines testing cost based on application and intensity. Transportation parameters are presented in Table 7.

Table 7. Transportation Modes

Location	Mode	Unit Size (Bushels)
Country Elevator		
Receiving	Truck	800
Loading	Rail	3,300
Export Elevator		
Receiving	Rail	3,300
Loading	Barge Hold	33,000
Importer Elevator		
Receiving	Barge Hold	33,000

Source: Wilson and Dahl, 2002.

Optimal Testing Parameters

The optimal testing strategy simultaneously chooses test application, intensity, and tolerance for intermediate points (country elevator, export elevator) subject to defined importer and domestic end-user tolerances. Tests may be applied at country elevator receiving, country elevator loading, export elevator receiving, and export elevator loading; however, they are required at the importer (base case) and domestic end-user. Test intensity is 1:1 (test every lot) at the importer and domestic end-user, but may vary from 1:1 to 1:5 (test every fifth lot) at intermediate points. Test tolerance for PCR and strip testing can be applied from .04% to 5% at intermediate points (See Table 6), but is predefined at the importer and domestic end-user from 0.5% to 5% with a base case of 1%.

Utility Parameters

The risk parameters λ, ϕ, and η were assumed to be 2, .01, and .5, respectively, for the base case.

Data

Data Sources

Data used in this research was obtained from the sources identified in Table 8.

Table 8. Data Sources

Model Component	Data Source
Utility Specification	Saha
Risk Premium	Serrao and Coelho
Adventitious Commingling Risk, Handling	Hurburgh; Casada, Ingles, and Maghirang
Adventitious Commingling Risk, Variety	Environmental Protection Agency
Variety Declaration	Survey of Market Participants (Wilson and Dahl, 2002)
Sampling Parameters	Winston
Binomial Specification	USDA-GIPSA 2000
Test Cost/Accuracy	Strategic Diagnostics, Inc. 2003 and Mid-West Seed Services, Inc.
Quality Loss	Taguchi
Transportation Modes	Wilson and Dahl, 2002

Simulation/Optimization Procedures

Risk Optimizer utilizes simulation and genetic algorithm-based optimization techniques to optimize models containing uncertainty. Probability distribution functions representing uncertainty are employed to define risk for model components and are entered into specific spreadsheet cells in lieu of a formula or number (Palisade).

Weighted disutility is defined as the target cell to be minimized via adjusting test application, test intensity, and test tolerance cells subject to constraints at the country elevator receiving/loading, and export elevator receiving/loading locations. Model constraints are specified for test application, test intensity, and test tolerance. Test application specifies whether a test is applied (Yes=1, No=0); test intensity specifies the frequency the test is applied (1:1, 1:2, 1:3, 1:4, 1:5); and test tolerance specifies the tolerance the test is applied (.04% to 5%). Subsequently, *Risk Optimizer* runs a full simulation for each potential trial solution generated by the genetic algorithm-based optimizer. Each iteration of a trial solution's simulation samples probability distribution functions to generate new values for the target cells. One thousand iterations are performed successively until distributions are adequately filled and simulated results are plausible (Palisade). Mutation rate is set at 0.2, crossover rate is 0.5, and only default operators are employed.

RESULTS AND SENSITIVITIES

Base Case Definition and Results

The base case is defined to reflect the most likely system and protocols for a dual marketing system. These include the following:

- Export shipment to importers
- GM adoption of 20% by farmers (based on market distributions of GM aversion)
- No variety declaration of GM content at country elevator
- The adventitious commingling risk due to the inability to distinguish GM content through variety declaration is 3 times the volume of unidentified GM delivered at the country elevator.
- Testing application is allowed at any or all of the following: Country Elevator (CE) receiving/loading, and at Export Elevator (EE) receiving/loading
- Tests applied at CE and EE locations utilize strip test technology
- Tests applied at the importer utilize PCR test technology
- Testing intensity is allowed to vary from 1 to 5 at the CE and EE
- Testing intensity is every unit at the importer
- Testing tolerance is allowed to vary from .04% to 5% at the CE and EE
- 1% importer tolerance specification
- $\lambda=2$, $\phi=0.01$, and $\eta=0.5$
- The penalty for exceeding the upper tolerance limit is 40-90 c/bu

The results (Table 9) identify the optimal testing strategy, accompanying costs, and risks that maximize utility (minimize disutility) of a dual marketing system versus a Non-GM system.

The optimal strategy is to test every other truckload at the country elevator when receiving at a 4% tolerance, test every railcar at the country elevator when loading at a 0.5% tolerance, and test ship hold at the export elevator when loading at a 0.5% tolerance. The sellers risk is the average rejection of Non-GM bushels delivered to the importer of 2.83%. The buyers risk is the 0.000154% of lots containing adventitious presence of GM in the importer flow after testing. The cumulative distribution of the probability of rejection at the importer is shown in Figure 4. The distribution of the probability of rejection identifies discrete levels of rejection at .015, .0275, and .04. Correspondingly, there is a 10%, 70%, and 90% probability of being less than 1.5%, 2.75%, and 4%, respectively.

The proportion of flows in the Non-GM channel declines from 80% at the farm level to 48% at the importer due to sampling, testing, and diversion of Non-GM lots containing adventitious presence of GM. The cumulative distribution of the proportion of flows at the importer is illustrated in Figure 5. The distribution of the proportion of flows indicates a 5% probability of being less than 46.3% and a 95% probability of being less than 49.7%.

Table 9. Base Case Results

	Base Case
Utility	1.0145
Optimal Strategy	
Test (1=yes, 0=no)-Intensity-Tolerance	
Country Elevator Receiving	1-2-4%
Country Elevator Loading	1-1-0.5%
Export Elevator Receiving	0-NA-NA
Export Elevator Loading	1-1-0.5%
Probabilities	
GM in Importer Flows (Buyer Risk)	.000154%
Rejection at Importer (Seller Risk)	2.83%
Costs (c/bu)	
Testing/All bu	0.68
Quality Loss/All bu	4.47
Testing/Non-GM bu	1.42
Quality Loss/Non-GM bu	9.36
Certainty Equivalent (Premium)	2.42
Total/All bu	7.57
Total/Non-GM bu	15.83
Location Percentage of Non-GM flow	
Adoption Rate	80.0%
Farmer in Bin	80.0%
Country Elevator Received	77.7%
Country Elevator Loaded	50.6%
Export Elevator Received	51.6%
Export Elevator Loaded	48.9%
Importer Received	48.0%

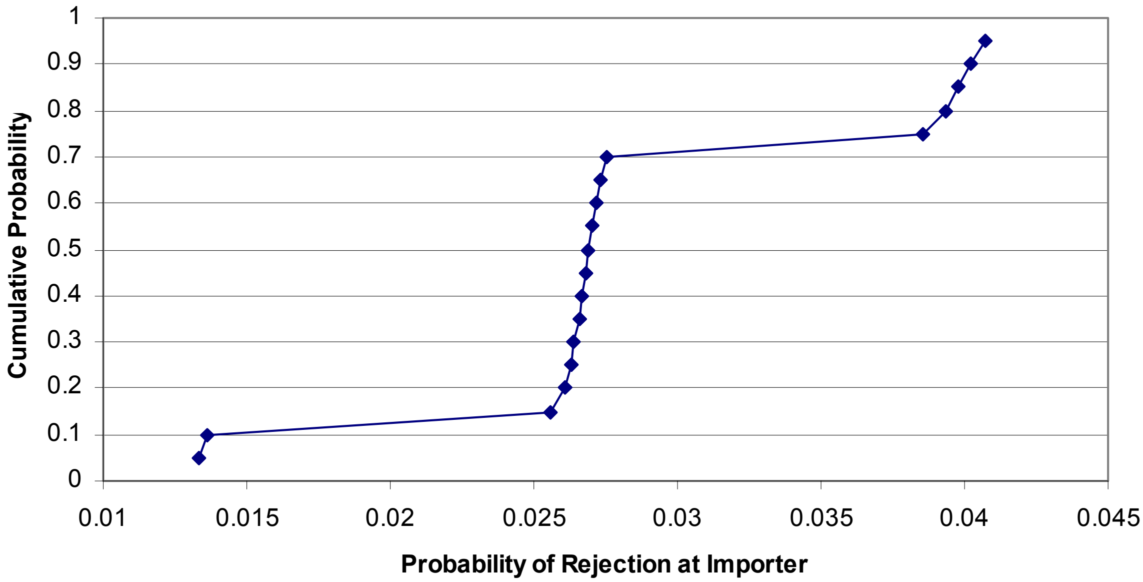

Figure 4. Base Case: Distribution of the Probability of Rejection at the Importer

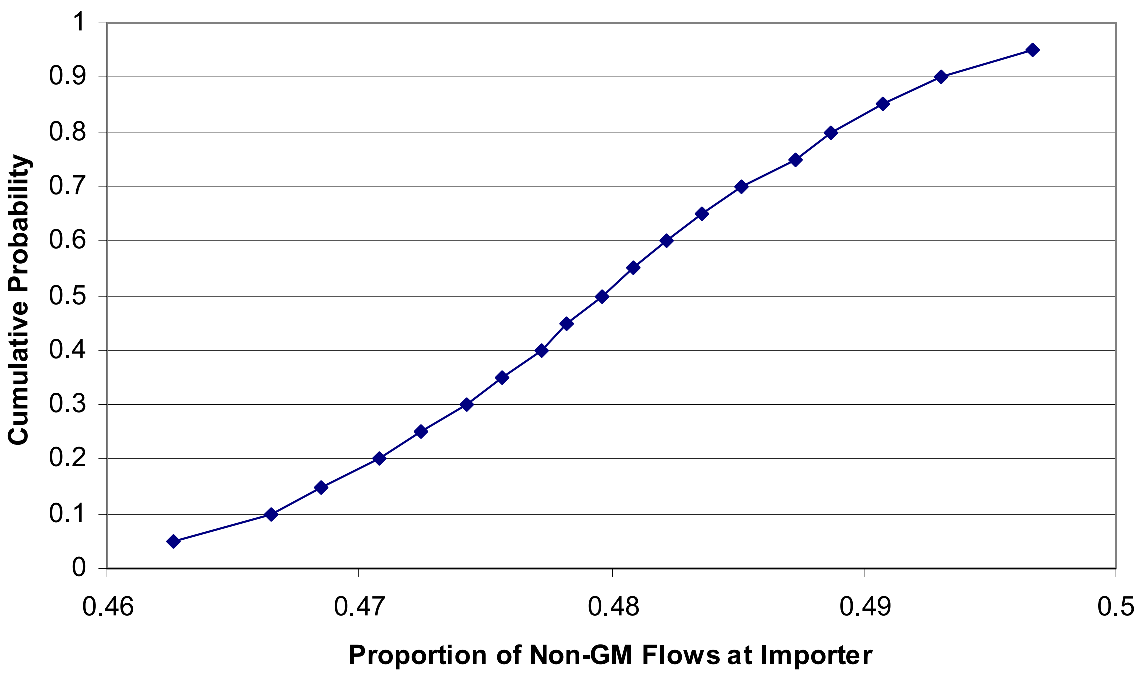

Figure 5. Base Case: Distribution of the Proportion of Non-GM Flows at the Importer

The utility of the base case is 1.0145, equating a certainty equivalent of 2.42 c/bu. This represents the premium required by the handler/shipper to be indifferent between the Non-GM/GM system with its accompanying test strategy (application, intensity, tolerance) and a Non-GM system. Alternatively, the premium reflects the perceived value of the additional risk incurred in a dual marketing system through handling GM and marketing Non-GM..

Testing and quality loss at the importer are 5.15 c/bu for all bushels. Components of cost include the following: testing every other truck with a 4% tolerance at country elevator receiving, .219 c/bu; testing every railcar with a 0.5% tolerance at country elevator loading, .082 c/bu; testing every barge hold with a 0.5% tolerance at export elevator loading, .006 c/bu; testing every barge hold at the importer, .38 c/bu; and quality loss at the importer of 4.47 c/bu. If attributed solely to Non-GM bushels, the cost escalates to 10.78 c/bu for testing and quality loss. In conjunction with the risk premium, total costs are 7.57 c/bu evaluated for all bushels and 15.83 c/bu evaluated for Non-GM bushels. These costs are inclusive of testing and quality loss within a dual marketing system and do not account for additional segregation, monitoring, etc. Figure 6 illustrates the cumulative distribution of additional system costs for Non-GM bushels. The distribution of additional system costs indicates a 5% probability of total costs being less than 3.98 c/bu and a 95% probability of being less than 39.35 c/bu.

Sensitivities on Stochastic Variables

Stochastic variables are used to demonstrate risks inherent in the dual marketing system. The primary uncertainty is adventitious presence of GM within the Non-GM flow and its potential impact on additional system costs arising from adventitious commingling risks, penalty differentials, and re-elevation discounts.

Adventitious Commingling at First Delivery

Adventitious commingling risks includes handling and shipping and those due to the inability to differentiate GM from Non-GM at the first point of delivery to the marketing system. Hurburgh et al. and Casada, Ingles, and Maghirang collectively quantify handling and shipping risks. However, without some method of distinguishing GM from Non-GM content, such as declaration of variety or GM content, whole lots of GM grain may be introduced to Non-GM segregations. EPA estimated adventitious commingling occurring with Starlink due to the inability to distinguish Starlink corn from Non-Starlink at first delivery. In the base case, handling, shipping, and variety risks utilized distributions provided in Table 4. However, the extent of risk due to the inability to distinguish GM from Non-GM at first delivery depends upon critical factors such as local percentages of GM and Non-GM grain, size and type of storage facilities, number of grain elevations, etc. To this end, the risk of commingling due to the inability to distinguish GM from Non-GM content was varied to determine impacts upon testing strategy, risks, and costs. Two cases are developed where commingling risk at first delivery was lower (2 * Unidentified GM) and a second with higher risk (3.5 * Unidentified GM). Results are presented in Table 10 for these alternative commingling risk cases.

The lower risk of adventitious commingling at first delivery model tests less intensively than the other cases, testing every unit at country elevator loading at a 5% tolerance, and every

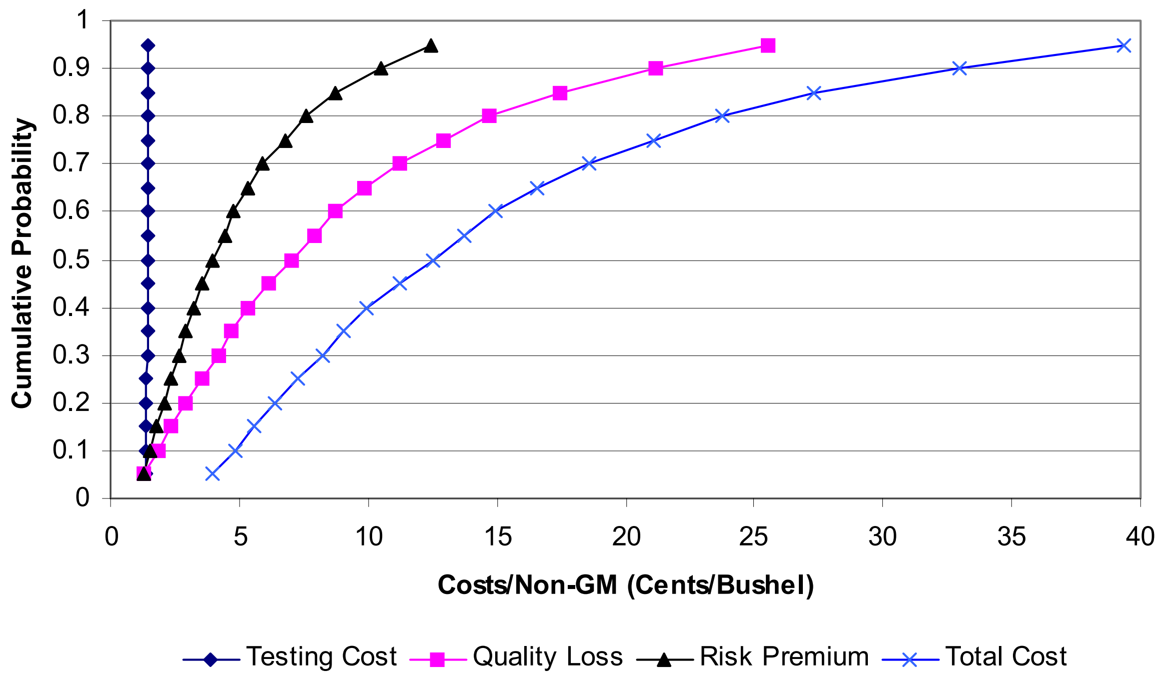

Figure 6. Base Case: Distribution of Additional System Costs

unit at export elevator loading at a 0.75% tolerance. The higher risk of adventitious commingling at first delivery model tests at the same intensity as the base case; however, testing tolerances are tighter at country elevator receiving and export elevator loading and looser at country elevator loading with an overall lower testing cost.

The probability of rejection at the importer is the highest for the model with lower risk of adventitious commingling at first delivery, 3.08% versus 2.83% in the base case and 3.03% for the model with higher risk of adventitious commingling. The degree of seller risk varies according to testing strategy; namely, the less intensive (lower cost) strategy results in higher rejection risk at the importer when importer specifications are unchanged. GM in importer flows is negligible.

Quality loss increased while testing costs declined for Non-GM bushels in both models with lower and higher risk of adventitious commingling at first delivery. Disutility increased as the rate of adventitious commingling at first delivery increased resulting in an increase in the risk premium required for decision makers to be indifferent between a Non-GM/GM or a Non-GM system. In addition, the percentage of Non-GM flows at the importer declined 8.75% and 6.04% from the base case for lower and higher risk of adventitious commingling at first delivery, respectively. The combinatorial nature of the abovementioned factors and discrete choice and utility theory results in higher Non-GM costs for lower and higher risk of adventitious commingling at first delivery as illustrated in Figure 7.

Table 10. Base Case Results and Sensitivity to Risk of Adventitious Commingling Due to Inability to Distinguish GM Content at First Delivery

Adventitious Commingling Risk at First Delivery (Multiple of GM Content Delivered and Accepted for Non-GM Segregations)	2*	Base Case 3*	3.5*
Utility	1.0144	1.0145	1.0147
Optimal Strategy			
Test (1=yes, 0=no)-Intensity-Tolerance			
Country Elevator Receiving	0-NA-NA	1-2-4%	1-2-3%
Country Elevator Loading	1-1-5%	1-1-0.5%	1-1-5%
Export Elevator Receiving	0-NA-NA	0-NA-NA	0-NA-NA
Export Elevator Loading	1-1-0.75%	1-1-0.5%	1-1-0.75%
Probabilities			
GM in Importer Flows (Buyer Risk)	.000293%	.000154%	.000152%
Rejection at Importer (Seller Risk)	3.08%	2.83%	3.03%
Costs (c/bu)			
Testing/All bu	0.46	0.68	0.66
Quality Loss/All bu	5.24	4.47	4.93
Testing/Non-GM bu	1.04	1.42	1.47
Quality Loss/Non-GM bu	12.01	9.36	10.98
Certainty Equivalent (Premium)	2.42	2.42	2.46
Total/All bu	8.12	7.57	8.06
Total/Non-GM bu	18.61	15.83	17.92
Location Percentage of Non-GM Flow			
Adoption Rate	80.0%	80.0%	80.0%
Farmer in Bin	80.0%	80.0%	80.0%
Country Elevator Received	100.0%	77.7%	77.7%
Country Elevator Loaded	46.6%	50.6%	47.7%
Export Elevator Received	47.6%	51.6%	48.8%
Export Elevator Loaded	44.6%	48.9%	46.0%
Importer Received	43.8%	48.0%	45.1%

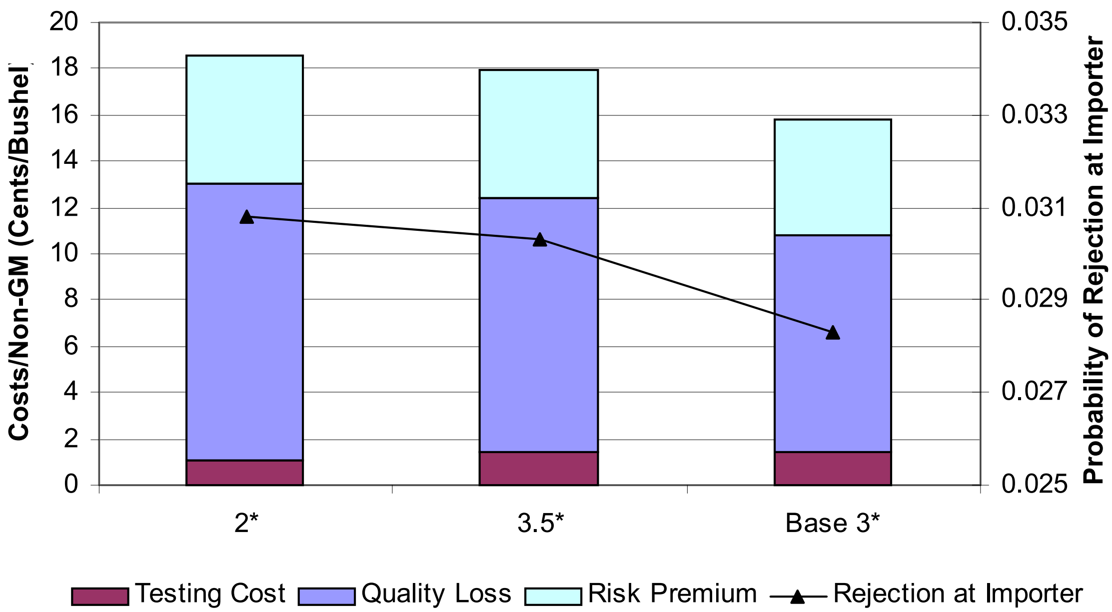

Figure 7. Effects of Variety Risk on Testing Cost, Quality Loss, Risk Premium and Importer Flow

Penalty Differentials (Discounts)

The base case assumed a discount (A_O = 40-90 c/bu) at the importer when the upper tolerance limit was exceeded. However, discounts or penalties are contract terms of individual buyers and through cumulative interaction of all buyers and sellers results in a competitive equilibrium. To illustrate, discounts are varied at the importer to reflect higher and lower values placed on non-conforming shipments. Two cases are developed, one with lower discounts (0-10 c/bu) and a second with higher discounts (100-150 c/bu). The results for discounts applied at the importer are presented in Table 11.

Lower penalties resulted in a less intensive testing strategy. Testing is performed on every unit at country elevator loading at a 5% tolerance and every unit at export elevator loading at a 0.5% tolerance. The less intensive testing strategy exposes the seller to additional risk of rejection at the importer, which increases from 2.83% in the base case to 4.57% with lower discounts. In contrast, higher penalties resulted in testing at fewer points compared to the base case but at greater intensities and tolerances. Testing is conducted on every unit at country elevator receiving at a 2% tolerance and every unit at export elevator loading at a 0.75% tolerance effectively reducing seller risk to 1.78% at the importer (Figure 8). GM in importer flows is negligible.

Table 11. Sensitivities to Importer Penalty Differentials

Penalty	0-10 c/bu	Base Case 40-90 c/bu	100-150 c/bu
Utility	1.0054	1.0145	1.0191
Optimal Strategy			
Test (1=yes, 0=no)-Intensity-Tolerance			
Country Elevator Receiving	0-NA-NA	1-2-4%	1-1-2%
Country Elevator Loading	1-1-5%	1-1-0.5%	0-NA-NA
Export Elevator Receiving	0-NA-NA	0-NA-NA	0-NA-NA
Export Elevator Loading	1-1-0.5%	1-1-0.5%	1-1-0.75%
Probabilities			
GM in Importer Flows (Buyer Risk)	.000233%	.000154%	.0000702%
Rejection at Importer (Seller Risk)	4.57%	2.83%	1.78%
Costs (c/bu)			
Testing/All bu	0.34	0.68	1.01
Quality Loss/All bu	0.82	4.47	4.76
Testing/Non-GM bu	1.18	1.42	1.38
Quality Loss/Non-GM bu	2.82	9.36	6.53
Certainty Equivalent (Premium)	0.33	2.42	4.18
Total/All bu	1.49	7.57	9.95
Total/Non-GM bu	5.15	15.83	13.65
Location Percentage of Non-GM flow			
Adoption Rate	80.0%	80.0%	80.0%
Farmer in Bin	80.0%	80.0%	80.0%
Country Elevator Received	100.0%	77.7%	77.7%
Country Elevator Loaded	31.5%	50.6%	77.7%
Export Elevator Received	32.8%	51.6%	78.2%
Export Elevator Loaded	29.7%	48.9%	74.3%
Importer Received	29.0%	48.0%	73.2%

Additional system costs increases for all bushels as higher penalties are imposed. Concurrent with testing intensity, testing cost increases 100% from the low penalty case to the base case, and 48.5% from the base case to the high penalty case. Similarly, quality loss increases 445% from the low penalty case to the base case and 7% from the base case to the high penalty case. Disutility for each of the cases increased as the penalty A_O increased and is reflected in the risk premium required for compensating handlers/shippers participating in a dual marketing system. With a penalty differential of 0-10 c/bu, the risk premium is .33 c/bu, but increases 633% to 2.42 c/bu for the base case, and another 72.7% to 4.18 c/bu for the high penalty case.

The percentage of Non-GM flows at the importer increases as higher penalties are prescribed with 29.04% Non-GM delivered in the low penalty case, 47.98% Non-GM delivered in the base case, and 73.24% Non-GM delivered in the high penalty case. Resultantly, additional system costs for Non-GM bushels are lower for the high penalty case versus the base case (Figure 8).

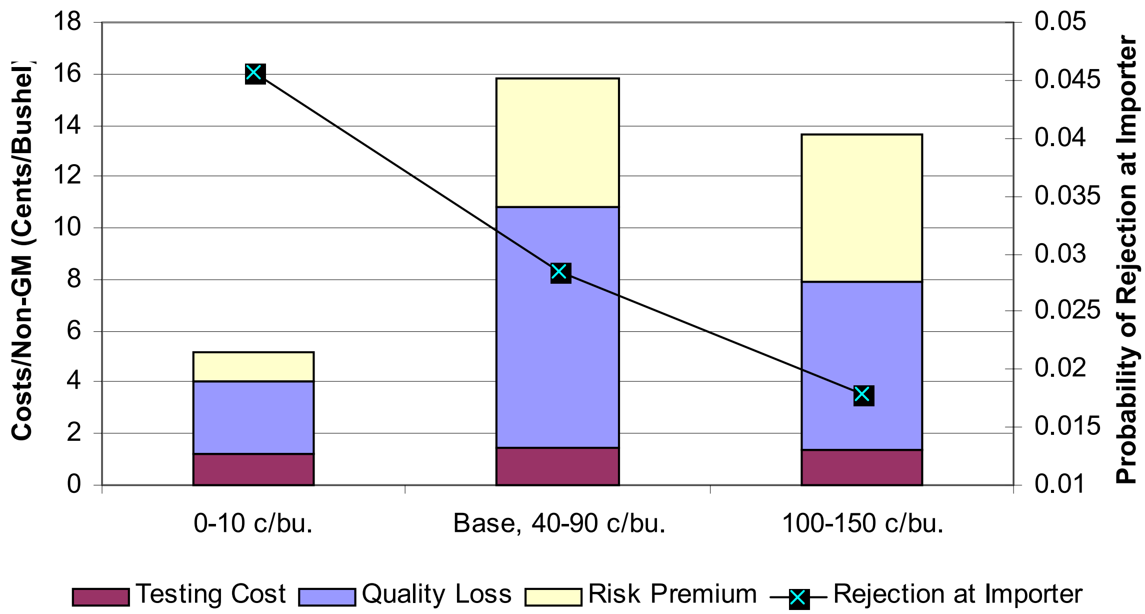

Figure 8. Effects of Penalty Differentials on Rejection Rates and Costs per Non-GM Bushel

Re-elevation and Re-elevation/Diverted GM Discounts

Cases are examined where discounts are applied at intermediate points for re-elevation and/or lots are identified as GM and diverted. In the first case, a re-elevation penalty (0-10 c/bu) is employed at country and export elevator loading to reflect the estimated cost of redirecting grain destined for shipment back to the facility. Penalties are not assigned at country elevator receiving and export elevator receiving because all grain is equally segregated at the point of origin.

A second case is developed that incorporates re-elevation discounts plus an assigned implicit cost for diverted GM grain along the marketing chain. A penalty of 5 c/bu is allocated to all GM lots that are diverted at country elevator loading and export elevator receiving and loading. Discounts for GM versus Non-GM grain may prevail; thus, the penalty effectively accounts for potential losses in marketing GM once ownership is taken. Table 12 presents re-elevation and re-elevation/GM discount cases with respect to the base case.

Re-elevation and re-elevation/diverted GM cases tested more intensively at country elevator receiving versus the base case, but avoided testing when loading at the country elevator. Testing was conducted on every unit at country elevator receiving at a 4% tolerance for the re-elevation case and 0.75% tolerance for the re-elevation/diverted case and on every unit at export elevator receiving at a 0.75% tolerance.

Table 12. Sensitivities to Re-elevation and Re-elevation/GM Discounts

Penalty	Base Case 0 c/bu	Re-elevation 0-10 c/bu	Re-elevation 0-10 c/bu, Diverted GM 5 c/bu
Utility	1.0145	1.0156	1.016
Optimal Strategy			
Test (1=yes, 0=no)-Intensity-Tolerance			
Country Elevator Receiving	1-2-4%	1-1-4%	1-1-1%
Country Elevator Loading	1-1-0.5%	0-NA-NA	0-NA-NA
Export Elevator Receiving	0-NA-NA	0-NA-NA	0-NA-NA
Export Elevator Loading	1-1-0.5%	1-1-0.75%	1-1-0.75%
Probabilities			
GM in Importer Flows (Buyer Risk)	.000154%	.0000702%	.0000702%
Rejection at Importer (Seller Risk)	2.83%	1.78%	1.78%
Costs (c/bu)			
Testing/All bu	0.68	1.01	1.21
Quality Loss/All bu	4.47	2.67	2.67
Testing/Non-GM bu	1.42	1.38	1.65
Quality Loss/Non-GM bu	9.36	3.66	3.66
Certainty Equivalent (Premium)	2.42	2.67	2.81
Total/All bu	7.57	6.35	6.68
Total/Non-GM bu	15.83	8.69	9.15
Location Percentage of Non-GM flow			
Adoption Rate	80.0%	80.0%	80.0%
Farmer in Bin	80.0%	80.0%	80.0%
Country Elevator Received	77.7%	77.7%	77.7%
Country Elevator Loaded	50.6%	77.7%	77.7%
Export Elevator Received	51.6%	78.2%	78.2%
Export Elevator Loaded	48.9%	74.3%	74.3%
Importer Received	48.0%	73.2%	73.2%

Testing cost for all bushels increased for both cases while the probability of rejection at the importer decreased from 2.83% in the base case to 1.78% for re-elevation and re-elevation/diverted GM cases. Quality loss decreased in both cases when compared to the base case for all bushels suggesting a tradeoff between testing cost and quality loss. GM in importer flows is negligible. Disutility increased as discounts escalated; hence, the risk premium also increased to account for additional risks to the handler/shipper for re-elevation and/or diverted GM grain charges. Total cost for Non-GM bushels decreased for both re-elevation and re-elevation/diverted GM cases reflecting a disproportionate decrease in quality loss versus increases in testing costs and risk premium. Compounding this effect are markedly higher Non-GM deliveries at the importer of 73.2% versus 48% in the base case. Figure 9 presents Non-GM costs and the probability of rejection at the importer.

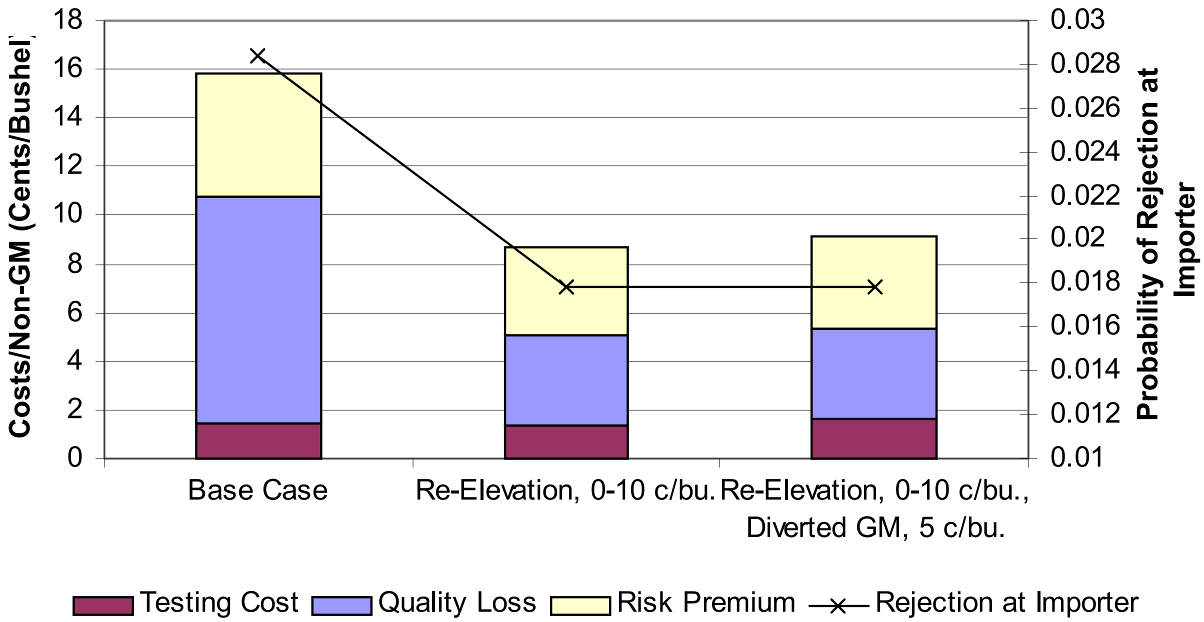

Figure 9. Effects of Re-elevation and Re-elevation/GM Diversion Costs on Costs/Non-GM and Percent of Flows at Importer

Sensitivities on Strategic Variables

Sensitivities on strategic variables are performed to determine changes in optimal testing strategies, risks, and costs when importers and handlers/shippers alter their strategic decisions. Strategic variables that are performed include import tolerance specifications and variety declaration contract mechanisms elicited by the handler/shipper.

Import Tolerance Specifications

In the base case, importers specified an upper tolerance limit of 1% GM lot concentration. Depending upon regulatory mandates, labeling requirements, end-user quality specifications, and commercial firm preferences, the tolerance designated at the importer may be tighter or looser. To illustrate, import tolerances were loosened and tightened to quantify additional system costs arising from each respective optimal strategy. To simulate the impact, five cases are developed with importer tolerances of 0.5%, 2%, 3%, 4%, and 5%. The range is inclusive of current industry practices; EU has set a level of 0.9% of all food and feed containing GM; other countries such as Japan, Taiwan, Thailand, Hong Kong, etc., require a 5% tolerance, while numerous countries mandate tolerances between 0.5% and 5% (Smyth and Phillips). The results are presented in Table 13.

Table 13. Sensitivities to Importer Tolerance Specification

Tolerance	0.5%	Base Case 1%	2%	3%	4%	5%
Utility	1.0253	1.0145	1.0086	1.0060	1.0052	1.0044
Optimal Strategy Test (1=yes, 0=no)-Intensity-Tolerance						
Country Elevator Receiving	1-1-1%	1-2-4%	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA
Country Elevator Loading	1-5-5%	1-1-0.5%	1-1-1%	1-1-2%	1-2-0.5%	1-2-1%
Export Elevator Receiving	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA
Export Elevator Loading	1-1-0.5%	1-1-0.5%	1-1-2%	1-1-2%	1-1-4%	1-1-1%
Probabilities						
GM in Importer Flows (Buyer Risk)	.0001 08%	.000154%	.000364%	.000152%	.000564%	.000341%
Rejection at Importer (Seller Risk)	1.93%	2.83%	4.35%	3.84%	6.07%	5.43%
Costs (c/bu)						
Testing/All bu	1.03	0.68	0.34	0.34	0.21	0.21
Quality Loss/All bu	9.64	4.47	2.64	1.17	1.47	0.94
Testing/Non-GM bu	1.41	1.42	1.18	1.17	1.12	1.11
Quality Loss/Non-GM bu	13.26	9.36	9.12	4.05	7.75	4.94
Certainty Equivalent (Premium)	7.66	2.42	0.84	0.43	0.31	0.22
Total/All bu	18.33	7.57	3.83	1.95	1.99	1.37
Total/Non-GM bu	25.19	15.83	13.20	6.71	10.51	7.17
Location Percentage of Non-GM flow						
Adoption Rate	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%
Farmer in Bin	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%
Country Elevator Received	77.7%	77.7%	100.0%	100.0%	100.0%	100.0%
Country Elevator Loaded	77.8%	50.6%	31.4%	31.4%	31.4%	31.4%
Export Elevator Received	78.2%	51.6%	32.8%	32.8%	32.8%	32.8%
Export Elevator Loaded	74.2%	48.9%	29.7%	29.7%	19.5%	19.5%
Importer Received	73.0%	48.0%	29.1%	29.3%	19.1%	19.2%

The optimal testing strategy becomes progressively less intensive as import tolerances are loosened from 0.5% to 5%. Testing is similar to the base case for a 0.5% import tolerance with the exception of test tolerances. Testing is conducted on every unit at country elevator receiving at a 1% tolerance, every 5th unit at country elevator loading at a 5% tolerance, and every unit at export elevator loading at a 0.5% tolerance. In contrast, the optimal testing strategies for import tolerances tighter than the base case preclude testing at country elevator receiving. The lack of test application at country elevator receiving exacerbates adventitious presence of GM within the Non-GM flow, primarily through adventitious commingling of high GM lot concentrations with Non-GM lots (see Table 4). The percentage of Non-GM flows at the importer significantly declines as import tolerances are loosened from 2% to 5%. Relative to the base case, the probability of rejection at the importer decreases for the 0.5% case, and increases for the 2%, 3%, 4%, and 5% case. GM in importer flows is negligible in all cases.

Disutility from additional system costs significantly decreases as tolerances are loosened. Hence, the risk premium required to compensate handlers/shippers is 7.66 c/bu for a 0.5% import tolerance, but progressively declines to 2.42 c/bu, 0.84 c/bu, 0.43 c/bu, 0.31 c/bu, and 0.22 c/bu for a 1%, 2%, 3%, 4%, and 5% import tolerance specification, respectively.

Relative to the base case, Non-GM testing costs increase for the 0.5% import tolerance case, and decrease for 2%, 3%, 4%, and 5% import tolerance cases illustrative of reduced non-conformance risk as tolerances are loosened. Quality loss for Non-GM bushels decreases 41.67% from the 0.5% import tolerance case to the base case, 2.63% from the base case to 2% import tolerance case, and 125% from the 2% import tolerance case to the 3% import tolerance case. Quality loss increases 91.36% from the 3% import tolerance case to the 4% import tolerance, and then decreases 56.88% from the 4% import tolerance case to the 5% import tolerance case. Increased quality loss at the 4% import tolerance can be attributed to the optimal testing strategy, which utilizes discrete choice and utility theory. Thus, the increased quality loss likely reflects a discrete change in the choice set of strategies; whereas, if choices were continuous, a strategy would likely be available part way between discrete choices where quality loss was lesser. Figure 10 illustrates the cumulative distribution of quality loss for various import tolerances.

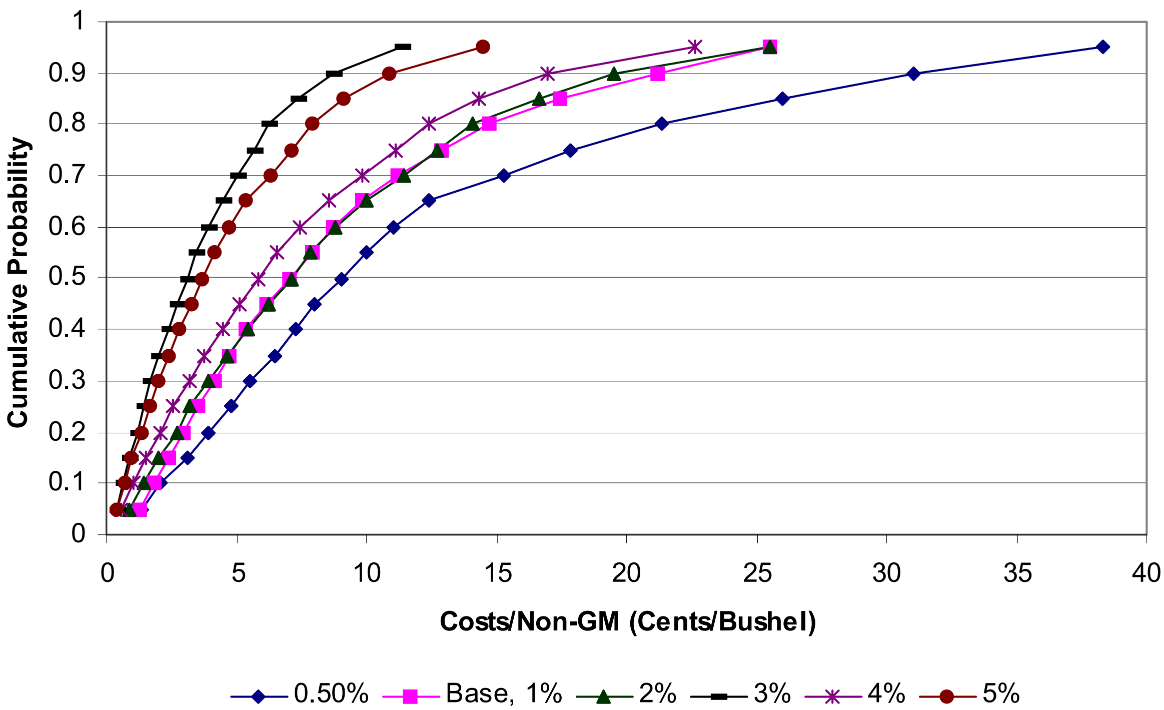

Figure 10. Distribution of Quality Loss

Total costs decrease as tolerance is loosened except at a 4% import tolerance, where cost slightly increases due to a different strategy being employed that trades off a decrease in testing cost for an increase in quality loss. Figure 11 graphically depicts additional system costs for Non-GM bushels and the percentage of Non-GM flows at the importer.

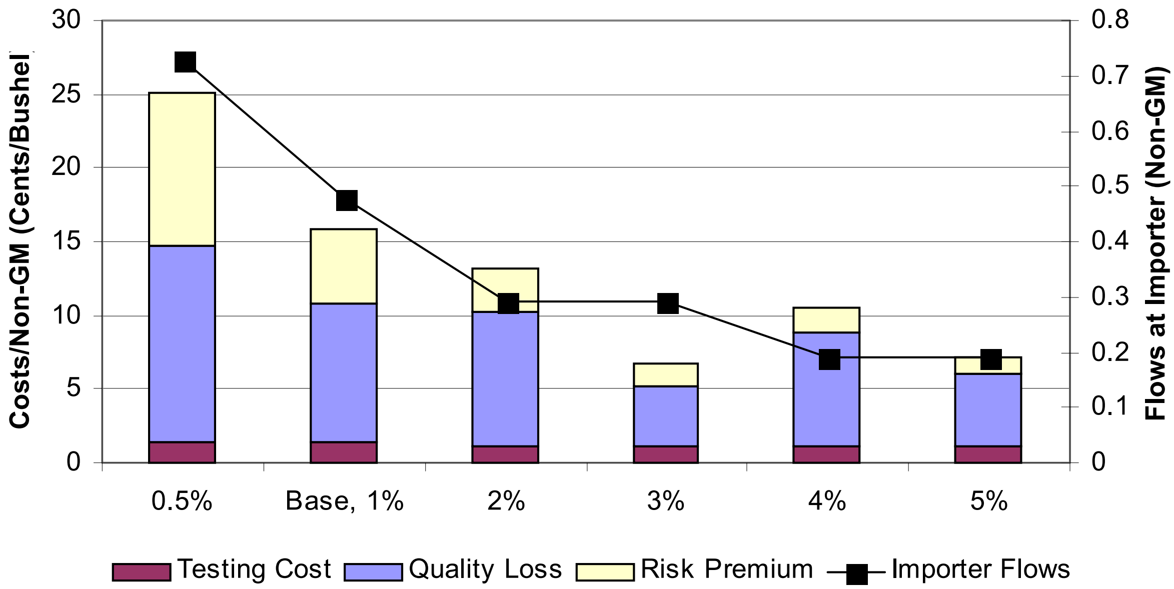

Figure 11. Effects of Importer Tolerances on Costs and Importer Flows for Non-GM Bushels

Variety Declaration

The base case scenario excludes mechanisms to elicit information from growers regarding the GM content of their grains. A system of contracts whereby growers sign affidavits to declare varieties as either Non-GM or GM would facilitate segregation at the point of first receipt. To examine the system's effectiveness, three models utilizing alternative distributions were developed with variety declaration that assumes minimum, most likely, and maximum values for farmer variety declaration at the point of origination. The alternatives have triangular distributions of: (40%, 50%, and 60%), (65%, 75%, and 85%) and (80%, 95%, and 100%). Results for these scenarios with variety declaration are presented in Table 14.

Table 14. Sensitivities to Variety Declaration

Variety Declaration	Base Case	40-50-60%	65-75-85%	80-95-100%
Utility	1.0145	1.0144	1.0141	1.0139
Optimal Strategy				
Test (1=yes, 0=no)-Intensity-Tolerance				
Country Elevator Receiving	1-2-4%	1-2-3%	0-NA-NA	0-NA-NA
Country Elevator Loading	1-1-0.5%	1-2-5%	1-2-1%	1-5-3%
Export Elevator Receiving	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA
Export Elevator Loading	1-1-0.5%	1-1-4%	1-1-4%	1-1-1%
Probabilities				
GM in Importer Flows (Buyer Risk)	0.000154%	0.000120%	0.000139%	0.000092%
Rejection at Importer (Seller Risk)	2.83%	2.53%	2.60%	2.15%
Costs (c/bu)				
Testing/All bu	0.68	0.67	0.47	0.51
Quality Loss/All bu	4.47	3.75	3.92	3.06
Testing/Non-GM bu	1.42	1.24	0.88	0.82
Quality Loss/Non-GM bu	9.36	7.01	7.50	4.97
Certainty Equivalent (Premium)	2.42	2.34	2.26	2.19
Total/All bu	7.57	6.75	6.64	5.77
Total/Non-GM bu	15.83	12.59	12.70	9.33
Location Percentage of Non-GM flow				
Adoption Rate	80.0%	80.0%	80.0%	80.0%
Farmer in Bin	80.0%	80.0%	80.0%	80.0%
Country Elevator Received	77.7%	77.7%	85.0%	81.7%
Country Elevator Loaded	50.6%	62.7%	63.4%	72.1%
Export Elevator Received	51.6%	63.4%	64.2%	72.7%
Export Elevator Loaded	48.9%	54.9%	53.7%	63.6%
Importer Received	48.0%	54.0%	52.8%	62.6%

With variety declaration, the optimal testing strategy becomes progressively less intensive as the rate of farmer variety declaration increases. This is due to less uncertainty surrounding variety identification and segregation. The low variety declaration model tested every other unit at country elevator receiving and loading at a 3% and 5% tolerance, respectively, and every unit at export elevator loading at a 4% tolerance. Conversely, the moderate variety declaration model avoided testing at country elevator receiving, but tested every other unit at country elevator loading at a 1% tolerance and every unit at export elevator loading at a 4% tolerance. Similarly, the high variety declaration model relaxed testing to every 5th unit at country elevator loading at a 3% tolerance and every unit at export elevator loading at a 1% tolerance.

The rejection at the importer decreased for all variety declaration cases relative to the base case. GM in importer flows is negligible. The percentage of Non-GM flows at the importer increases for variety models reflecting less diversion at the country elevator. Total costs for Non-GM bushels decreases from 15.83 c/bu in the base case to 12.59 c/bu for the low variety declaration model, increases to 12.7 c/bu for the moderate variety declaration model, and decreases to 9.33 c/bu for the high variety declaration model. However, when measured across all bushels, cost is inversely proportional to the level of variety declaration. The risk premium similarly decreases with higher levels of variety declaration due to a continued decrease in disutility. Since current grain margins have evolved to approximately 2.5 c/bu, the development of a contract mechanism for variety declaration is essential. Additional system costs for Non-GM bushels and the probability of rejection at the importer are shown in Figure 12.

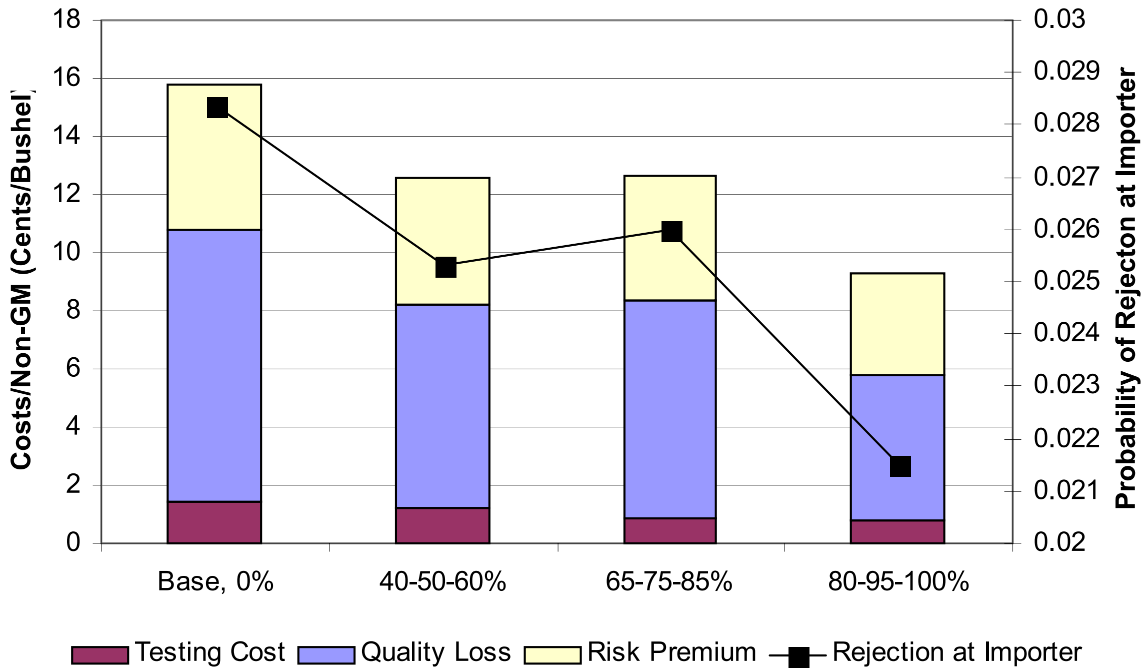

Figure 12. Effects of Variety Declaration on Costs/Non-GM and Importer Rejection

Sensitivities on Parametric Variables

Parametric variables include risk aversion η and GM adoption rate.

Risk Aversion (η)

The risk parameter η will inevitably vary amongst handlers/shippers depending upon their aversion to risk. Correspondingly, sensitivities are conducted for the base case with more and less risk aversion to illustrate the tradeoff between testing cost and quality loss. Two cases, $\eta=0.9$ (more risk averse) and $\eta=0.4$ (less risk averse) are developed, and the optimal testing strategy, risks, and costs are contrasted with the base case ($\eta=0.5$). The results are presented in Table 15.

Table 15. Sensitivities to Risk Aversion (η)

Risk Aversion	0.4	Base Case, 0.5	0.9
Utility	1.0112	1.0145	1.0281
Optimal Strategy			
Test (1=yes, 0=no)-Intensity-Tolerance			
Country Elevator Receiving	0-NA-NA	1-2-4%	1-1-0.5%
Country Elevator Loading	1-1-0.5%	1-1-0.5%	1-5-5%
Export Elevator Receiving	0-NA-NA	0-NA-NA	0-NA-NA
Export Elevator Loading	1-1-0.75%	1-1-0.5%	1-1-0.75%
Probabilities			
GM in Importer Flows (Buyer Risk)	0.000367%	0.000154%	0.000137%
Rejection at Importer (Seller Risk)	4.55%	2.83%	1.76%
Costs (c/bu)			
Testing/All bu	0.34	0.68	1.03
Quality Loss/All bu	10.57	4.47	2.39
Testing/Non-GM bu	1.18	1.42	1.41
Quality Loss/Non-GM bu	36.50	9.36	3.29
Certainty Equivalent (Premium)	1.63	2.42	3.28
Total/All bu	12.54	7.57	6.70
Total/Non-GM bu	43.30	15.83	9.19
Location Percentage of Non-GM flow			
Adoption Rate	80.0%	80.0%	80.0%
Farmer in Bin	80.0%	80.0%	80.0%
Country Elevator Received	100.0%	77.7%	77.7%
Country Elevator Loaded	31.4%	50.6%	77.7%
Export Elevator Received	32.8%	51.6%	78.2%
Export Elevator Loaded	29.7%	48.9%	74.2%
Importer Received	29.0%	48.0%	73.2%

The optimal testing strategies intensify from the less risk averse case to the more risk averse case indicating a preference shift for testing cost versus quality loss and rejection at the importer. Testing for the less risk averse case is conducted on every unit at country and export elevator loading locations at a 0.5% and .75% tolerance, respectively. The more risk averse case tests every unit at country elevator receiving at a 0.5% tolerance, every 5th unit at country elevator loading at a 5% tolerance, and every unit at export elevator loading at a 0.75% tolerance.

The rejection rate at the importer is the highest for the less averse case, 4.55% versus 2.83% in the base case and 1.76% in the more risk averse case. In addition, the percentage of Non-GM flows is the lowest for the less risk averse case, 29% in contrast to 48% for the base case and 73.2% for the more risk averse case. The large diversion of Non-GM flows occur primarily at country elevator loading for the less risk averse case since testing is not conducted at country elevator receiving.

Disutility for each of the cases increased as the risk parameter η was increased indicating an increased propensity to avoid quality loss uncertainty. With η=0.9 the risk premium is 3.28 c/bu, but declines to 1.63 c/bu when η=0.4. More risk averse handlers/shippers discount additional testing cost and quality loss more than less averse shippers and, consequently, require a higher premium to participate in a dual marketing system.

Total system costs decrease across Non-GM/all bushels as risk aversion increases. Testing cost for Non-GM/all bushels increases while quality loss decreases from the less risk averse case to the more risk averse. The less risk averse handler/shipper is willing to incur high quality loss with uncertainty to avoid testing cost with certainty; conversely, the more risk averse handler/shipper prefers to test more intensively and reduce quality loss. The preference of the handler/shipper largely determines the optimal testing strategy and resulting tradeoffs between testing cost and quality loss; thus, risk aversion (η) is a critical parameter in the analysis. Figure 13 illustrates the proponents of additional system costs for Non-GM bushels and the probability of rejection at the importer.

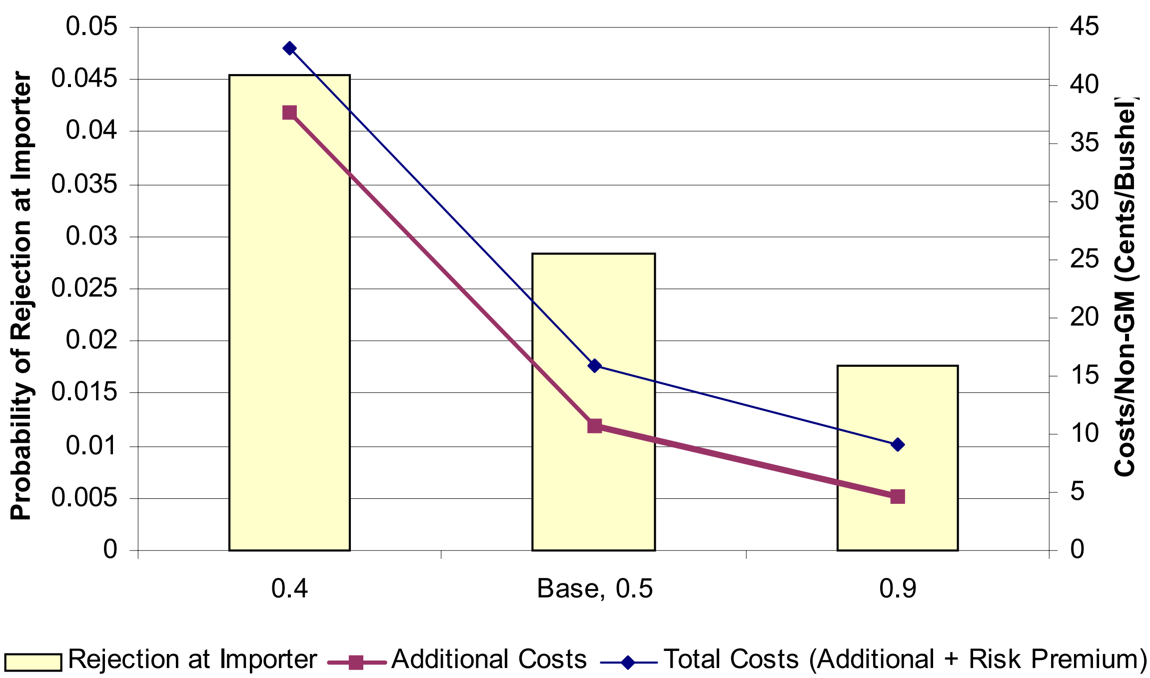

Figure 13. Effect of Risk Aversion Parameter η on Importer Rejection and Additional and Total Costs per Non-GM Bushel

GM Adoption

In the base case, a 20% GM adoption rate is assumed approximating that of GM corn. However, the level of GM adoption by farmers is uncertain and depends upon factors such as import restrictions, agronomic benefits, existence of a viable testing and segregation strategy, variety declaration, etc. To illustrate, prospective cases are developed for no variety declaration and variety declaration (85-95-100%) that increase or decrease the level of GM adoption. For no variety declaration, the low adoption case assumes 10% GM adoption, while the high adoption case assumes 25% GM adoption. A 30% GM adoption case was simulated, but prohibitive costs indicated that if GM adoption rates evolve to greater than 25%, variety declaration becomes essential. For variety declaration, four cases including 25%, 50%, 60%, and 70% GM adoption are examined. Additionally, a 75% GM adoption case was simulated, but prohibitive costs indicated that if GM adoption is greater than 70%, an alternative system of testing and segregation must be adopted. The results for the no variety declaration cases are in Table 16.

Table 16. Sensitivities of No Variety Declaration to GM Adoption

GM Adoption	10%	Base Case, 20%	25%
Utility	1.0140	1.0145	1.0150
Optimal Strategy			
Test (1=yes, 0=no)-Intensity-Tolerance			
Country Elevator Receiving	0-NA-NA	1-2-4%	1-2-4%
Country Elevator Loading	1-1-5%	1-1-0.5%	1-1-0.5%
Export Elevator Receiving	0-NA-NA	0-NA-NA	0-NA-NA
Export Elevator Loading	1-1-1%	1-1-0.5%	1-1-0.5%
Probabilities			
GM in Importer Flows (Buyer Risk)	0.000119%	0.000154%	0.000215%
Rejection at Importer (Seller Risk)	2.34%	2.83%	3.48%
Costs (c/bu)			
Testing/All bu	0.56	0.68	0.61
Quality Loss/All bu	3.37	4.47	6.28
Testing/Non-GM bu	0.98	1.42	1.56
Quality Loss/Non-GM bu	5.86	9.36	16.12
Certainty Equivalent (Premium)	2.23	2.42	2.60
Total/All bu	6.16	7.57	9.49
Total/Non-GM bu	10.71	15.83	24.36
Location Percentage of Non-GM flow			
Adoption Rate	90.0%	80.0%	75.0%
Farmer in Bin	90.0%	80.0%	75.0%
Country Elevator Received	100.0%	77.7%	72.9%
Country Elevator Loaded	60.9%	50.6%	41.5%
Export Elevator Received	61.7%	51.6%	42.7%
Export Elevator Loaded	58.7%	48.9%	29.9%
Importer Received	57.8%	48.0%	39.1%

The low adoption case averts testing at country elevator receiving and tests at a looser tolerance at country and export elevator loading compared to the base case. Alternately, the high adoption case tests the same as the base case at country elevator receiving and loading and export elevator loading. At 30% GM adoption with no variety declaration, the defined system of testing and segregation becomes cost prohibitive irrespective of the testing strategy.

The probability of rejection at the importer is directly proportional to the level of GM adoption; thus, rejection risk is 2.34% for the low adoption case, 2.83% for the base case, and 3.48% for the high adoption case. GM in importer flows is negligible.

Total costs attributed to Non-GM bushels decreases to 10.71 c/bu for the low adoption case, 15.83 c/bu for the base case, and increases to 24.36 c/bu for the high adoption case compared to the base case. Testing cost increases from 0.98 c/bu in the low adoption case to 1.42 c/bu in the base case, and 1.56 c/bu in the high adoption case. Similarly, quality loss escalates from 5.86 c/bu in the low adoption case to 16.12 c/bu in the high adoption case. The increase in both testing cost and quality loss stems from additional GM in the system commingling adventitiously with a larger proportion of Non-GM flows.

Firms segregating both Non-GM/GM flows experience increased GM adventitious commingling risk from higher adoption without variety declaration. Consequently, disutility increases from the low adoption case to the high adoption case necessitating a larger required risk premium for handlers/shippers.

The percentage of flows at the importer decreased as adoption rates increased reflecting lower initial percentages of Non-GM. In the low adoption case, 57.8% flows were delivered to the importer as Non-GM versus 48% for the base case, and 39.1% for the high adoption case. Figure 14 illustrates costs for Non-GM bushels and the probability of rejection at the importer.

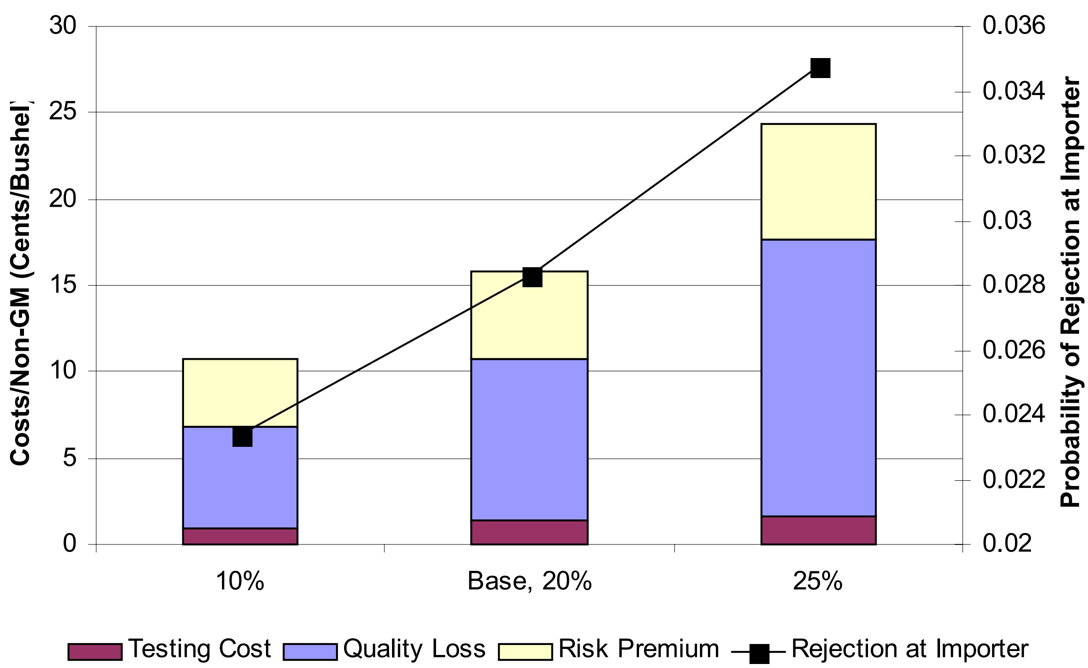

Figure 14. Effects of GM Adoption on Non-GM Costs and Importer Rejection with No Variety Declaration

The results for GM adoption in the variety declaration cases are presented in Table 17.

Table 17. Sensitivities of Variety Declaration to GM Adoption

GM Adoption	Base Case, 20%	25%	50%	60%	70%
Utility	1.0145	1.0139	1.0145	1.0151	1.0162
Optimal Strategy					
Test (1=yes, 0=no)-Intensity-Tolerance					
Country Elevator Receiving	1-2-4%	0-NA-NA	1-1-1%	1-1-2%	1-1-3%
Country Elevator Loading	1-1-0.5%	1-2-5%	1-5-5%	0-NA-NA	0-NA-NA
Export Elevator Receiving	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA
Export Elevator Loading	1-1-0.5%	1-1-2%	1-1-0.75%	1-1-0.75%	1-1-0.75%
Probabilities					
GM in Importer Flows (Buyer Risk)	0.000154%	0.000144%	0.00022%	0.000384%	0.000286%
Rejection at Importer (Seller Risk)	2.83%	2.30%	2.97%	3.69%	4.87%
Costs (c/bu)					
Testing/All bu	0.68	0.51	0.61	0.49	0.38
Quality Loss/All bu	4.47	3.32	4.75	7.12	12.03
Testing/Non-GM bu	1.42	0.86	1.34	1.35	1.40
Quality Loss/Non-GM bu	9.36	5.73	10.47	19.67	44.71
Certainty Equivalent (Premium)	2.42	2.20	2.38	2.66	3.14
Total/All bu	7.57	6.03	7.73	10.26	15.55
Total/Non-GM bu	15.83	10.37	17.06	28.36	57.79
Location Percentage of Non-GM flow					
Adoption Rate	80.0%	75.0%	50.0%	40.0%	30.0%
Farmer in Bin	80.0%	75.0%	50.0%	40.0%	30.0%
Country Elevator Received	77.7%	77.1%	48.6%	38.9%	29.1%
Country Elevator Loaded	50.6%	66.3%	48.6%	38.9%	29.1%
Export Elevator Received	51.6%	67.0%	49.6%	40.1%	30.6%
Export Elevator Loaded	48.9%	59.9%	46.3%	37.0%	27.6%
Importer Received	48.0%	58.9%	47.2%	36.2%	27.0%

The optimal testing strategies became less intensive for GM adoption rates higher than the base case. The 25% case precluded testing at country elevator receiving and tested at the country and export elevator. The base case and 50% case performed testing at country elevator receiving and loading and export elevator loading, while the 60% and 70% cases tested at country elevator receiving and export elevator loading.

Relative to the base case of 2.83%, rejection at the importer decreased to 2.30% for the 25% case, and progressively increased to 2.97%, 3.69%, and 4.87% for the 50%, 60%, and 70% cases, respectively. GM in importer flows is negligible.

Total cost for Non-GM bushels decreased for the 25% case due to a decrease in testing costs, quality loss, and risk premium, and an increase in percentage of Non-GM flows at the importer relative to the base case. Conversely, total cost increased for the 50%, 60%, and 70% cases relative to the base case. The increase in total cost originated from an increase in quality loss and risk premium and a decrease in the percentage of Non-GM flows at the importer. Total cost surges at progressively higher GM adoption rates and eventually becomes cost prohibitive at 75% GM adoption, suggesting an upper bound to the defined system of testing and segregation. Figure 15 shows total cost for Non-GM bushels and probability of rejection at the importer.

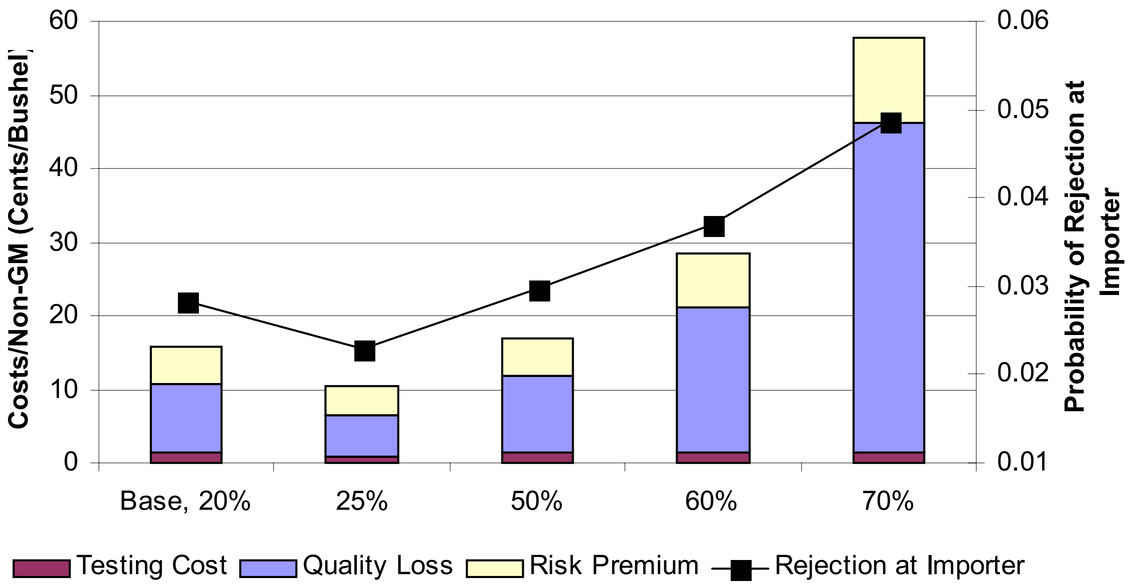

Figure 15. Effects of GM Adoption on Costs and Importer Flows for Non-GM Bushels with Variety Declaration

Domestic System

The base case examines the impacts on optimal testing strategies, risks, and costs of a dual marketing system with delivery to importers. Alternatively, if the end-user is domestically located, it entails less handling, transportation, and subsequent adventitious commingling risk. Models with no variety declaration and variety declaration using *Risk Triangle* 80-95-100% are developed to examine the effects of delivery to a domestic market.

The optimal strategy determines test application, intensity, and tolerance for country elevator receiving and country elevator loading using a strip test. Domestic user receiving requires testing on every unit using a PCR test. The penalty for non-conformance at the domestic end-user is 2-20 c/bu, reflecting discounts and or re-routing of grain. Other parameters are as previously defined for the base case. The results are presented in Table 18.

Table 18. Domestic System

	No Variety Declaration	Variety Declaration
Utility	1.0120	1.0079
Optimal Strategy		
Test (1=yes, 0=no)-Intensity-Tolerance		
Country Elevator Receiving	1-4-0.75%	0-NA-NA
Country Elevator Loading	1-5-0.75%	1-4-0.5%
Export Elevator Receiving	NA	NA
Export Elevator Loading	NA	NA
Probabilities		
GM in Importer Flows (Buyer Risk)	NA	NA
Rejection at Importer (Seller Risk)	NA	NA
GM in Domestic User Flow (Buyer Risk)	0.0127%	0.0895%
Rejection at Domestic User (Seller Risk)	3.59%	1.98%
Costs (c/bu)		
Testing/All bu	0.36	0.16
Quality Loss/All bu	3.33	0.90
Testing/Non-GM bu	0.72	0.23
Quality Loss/Non-GM bu	6.70	1.26
Certainty Equivalent (Premium)	1.79	0.75
Total/All bu	5.48	1.81
Total/Non-GM bu	11.02	2.54
Location Percentage of Non-GM flow		
Adoption Rate	80.0%	80.0%
Farmer in Bin	80.0%	80.0%
Country Elevator Received	77.7%	81.7%
Country Elevator Loaded	50.6%	72.2%
Export Elevator Received	NA	NA
Export Elevator Loaded	NA	NA
Importer Received	NA	NA
Domestic User Received	49.8%	71.3%

The domestic case under no variety declaration tested less intensively than the base case, testing every 4th unit at country elevator receiving at a 0.75% tolerance and every 5th unit at country elevator loading at a 0.75% tolerance. The variety declaration case tested even less intensively than the no variety declaration case, testing every 4th unit at country elevator loading at a 0.5% tolerance. The probability of rejection at the domestic user increased to 3.59% for the no variety declaration case, but decreased to 1.98% for the variety declaration case. Additional system costs across Non-GM bushels decreased 4.81 c/bu and 13.29 c/bu relative to the base case for no variety and variety declaration cases, respectively.

The increase in the probability of rejection at the domestic user under no variety declaration is attributable to adventitious commingling at country elevator loading and the inability of the system to divert all GM flows from the Non-GM flow prior to domestic user inspection. Conversely, the decreases in additional system cost results from lesser penalties for non-conformance and reduced adventitious commingling from handling and shipping. The percent of Non-GM flows for the 49.8% no variety declaration case and 71.3% for the variety declaration case. GM in domestic flows after rejection is negligible for both cases.

Total costs substantially decrease across all and Non-GM bushels in the domestic case, reflecting lower testing costs, quality losses, and required risk premium. Testing cost across Non-GM bushels decreased from 1.42 c/bu in the base case to 0.72 c/bu and 0.23 c/bu for the no variety and variety declaration cases, respectively. In addition, quality loss across Non-GM bushels decreased from 9.36 c/bu in the base case to 6.70 c/bu for the no variety declaration case and 1.26 c/bu for the variety declaration case. Furthermore, disutility decreased equating a risk premium of 1.79 c/bu and 0.75 c/bu for no variety and variety declaration cases, respectively. The results indicate that additional system costs are less for both cases, although the probability of rejection is higher for the no variety declaration case due to lower penalties for non-conformance. The incentive for establishing contract mechanisms is illustrated via an 8.48 c/bu differential between the no variety and variety declaration cases. Figure 16 illustrates the probability of rejection at the importer and total costs across Non-GM bushels.

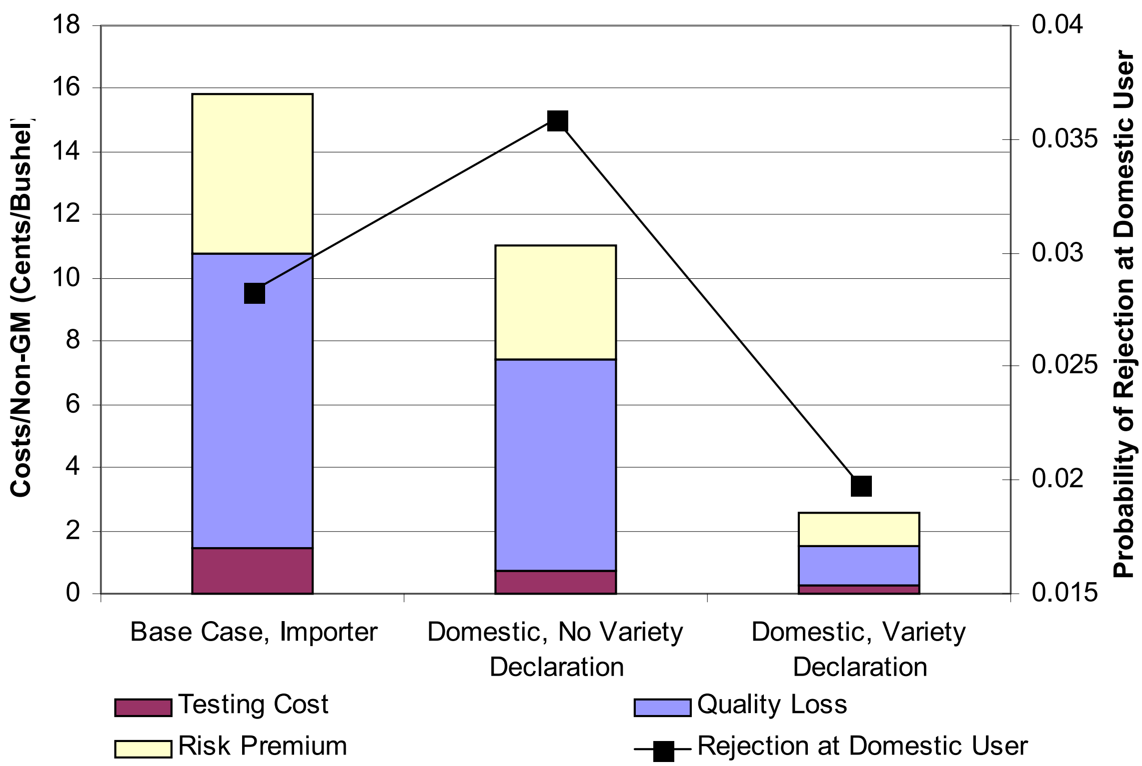

Figure 16. Effects of a Domestic versus Import System on Costs/Non-GM and Rejection at End-User

CONCLUSIONS

Segregation of like varieties with particular attributes exists to avoid commingling and value-added losses. The introduction of transgenic varieties has necessitated additional testing and segregation to avert contamination at production, loading, unloading, storage, and transportation phases of grain movement. Segregation costs included in the research were testing costs and risk premiums required to compensate handlers/shippers for risk of non-conformance at the end-user. Infrastructure modifications, storage utilization, and additional costs of segregation are not considered.

Importers and domestic end-users designate tolerance limits of genetically modified grain. These are governed through regulatory guidelines and commercial firm preferences. Typically, non-conforming grain shipments incur a discount or are rejected when tolerance exceeds end-user specifications. Quality loss was included in the research to assess both the extrinsic and intrinsic value of Non-GM lots containing adventitious presence of GM at the end-user.

The objective of this research was to evaluate the optimal testing strategy encompassing test application, intensity, and tolerance for a dual marketing system consisting of Non-GM and GM flows. A stochastic optimization model was constructed utilizing an objective function that maximizes portfolio utility (minimizes portfolio disutility) of additional system costs for a grain marketing channel handling two states of nature (Non-GM and GM). The model determined the optimal testing application, intensity, and tolerance to employ at country elevator receiving, country elevator loading, export elevator receiving, and export elevator loading subject to a specified tolerance at the end-user. Tests can be applied at any point in the marketing channel with varying discrete intensities and tolerances (.04% to 5%). PCR tests were required on every lot at the end-user, while strip tests were applied based on testing strategy at country and export elevators concurrent with industry practices. The percentage of Non-GM and GM flows was tracked throughout the system and used in calculating portfolio disutility.

Summary of Results

The optimal testing strategy simultaneously determined test application, intensity, and tolerance that minimized disutility of additional system costs for a portfolio of segregations. The model identified system costs through total costs across all bushels and Non-GM bushels. Various sensitivities were performed to determine how stochastic, strategic, parametric, and other variables affected optimal testing strategies, risks, and costs. Stochastic sensitivities included risk of adventitious commingling at first delivery, penalty differentials, and re-elevation/diverted GM discounts. Strategic sensitivities included import tolerance specifications and variety declaration. Parametric sensitivities included risk aversion and GM adoption. A final sensitivity evaluated the effect of a domestic versus import system.

Stochastic Sensitivities

The main benefit to performing sensitivities on stochastic variables was to assess changes in optimal testing strategies, risks, and costs from random probability distributions. Sensitivities of stochastic variables are examined in succeeding sections and variations are compared with base case results.

- **Adventitious Commingling at First Delivery.** Costs and risks increased as the rate of adventitious commingling at first delivery deviated from the base case due to the inability to distinguish GM from Non-GM content. Increased risk of adventitious commingling at first delivery increased total costs through increases in testing cost, quality loss, and risk premium. Probability of rejection at importer also increased, while the percentage of Non-GM flows decreased. Similarly, lower risk of adventitious commingling at first delivery increased total costs, albeit decreases in testing and risk premium components. The lower risk case exhibited increases in quality loss and thus total cost due to no testing at country elevator receiving. Correspondingly, the probability of rejection at the importer increased and importer Non-GM flows decreased.

- **Penalty Differentials (Discounts).** Penalties varied from 0-10 c/bu for the low penalty case to 100-150 c/bu for the high penalty case at the importer. Total cost for all bushels trended upwards as penalties were increased. The most pronounced effect occurred in the risk premium, which increased from 0.33 cu/bu for the low penalty case to 4.18 c/bu in the high penalty case, reflecting a higher cost/risk for non-conforming lots. Testing cost and quality loss exhibited similar increases. However, when costs were attributed to Non-GM bushels, total cost declined for the high penalty case compared to the base case. The percentage of Non-GM flows at the importer were 29% for the low penalty case, 48% for the base case, and 73.2% for the high penalty case. The probability of rejection at the importer decreased as penalties increased, providing evidence of the tradeoff between testing cost and seller risk.

- **Re-elevation and Re-elevation/Diverted GM Discounts.** Re-elevation and re-elevation/diverted GM discount cases were incorporated to reflect re-elevation costs at country and export elevator loading and discounts for diverting GM lots at country elevator loading and export elevator receiving and loading. For the re-elevation case, total cost decreased due to increased testing at country elevator receiving. The re-elevation/diverted GM discount case tested more intensively than the re-elevation case increasing total costs relative to the re-elevation case, but decreasing total cost compared to the base case. Both cases decreased the probability of rejection at the importer from 2.83% in the base case to 1.78% and increased Non-GM flows at the importer to 73.2%. Handlers/shippers required progressively larger risk premiums as re-elevation and re-elevation/diverted GM discounts were added, providing evidence that re-elevation and marketability of grain are critical factors.

Strategic Sensitivities

Strategic decisions by importers and commercial firms have implications for optimal testing strategies, risks, and costs in a system. The following sections examine sensitivities on strategic variables, and variations are compared with base case results.

- **Import Tolerance Specifications.** Importers designate tolerances based on government mandates and their preferences. Firms may specify tighter tolerances then necessary based on consumer preferences and value-added market potential for differentiating products. Importer tolerances of 0.5%, 2%, 3%, 4%, and 5% were examined relative to the base case tolerance of 1%. In general, total costs decreased as tolerances were loosened with the exception of the 4% tolerance, which slightly increased due to a different testing strategy. Testing costs increased for the 0.5% case and then decreased for tolerances looser than the base case. Quality loss decreased as tolerances were loosened with the exception of the 4% tolerance, which slightly increased. As expected, the risk premium required for handlers/shippers significantly decreased with a looser tolerance specification. This reveals that loosely specified tolerances for GM could be attained with little additional risk imparted to the handler/shipper. Ironically, the percentage of Non-GM flows at the importer decreased as tolerance was loosened. This was mainly due to large diversions at country elevator loading from variety risk since testing was not conducted at country elevator receiving for 2%, 3%, 4%, and 5% cases. The probability of rejection at the importer generally decreased when tolerance was tightened and increased when tolerance was loosened; however, it decreased from the 2% case to the 3% case and again from the 4% case to the 5% case. This is due to similar testing strategies for 2% and 3% tolerances and 4% and 5% tolerances and the corresponding decrease in tolerance within each range.

- **Variety Declaration.** Contract mechanisms were adopted to elicit information from farmers regarding the GM content of their grains. The level of farmer variety declaration assumed a *Risk Triangle* distribution representing minimum, most likely, and maximum values. Three models were developed including a 40-50-60%, 65-75-85%, and 80-95-100% case to indicate the probability that farmers will tell the truth. Higher levels of variety declaration decreased total costs across all bushels. Total cost across Non-GM bushels also decreased except for the moderate case where they slightly increased due to the percentage of Non-GM flows at the importer. The total cost spread between the base case and the high variety declaration case was 6.5 c/bu across Non-GM bushels. It can be viewed as the value to implementing contract mechanisms for variety declaration. Testing cost and quality loss generally declined for higher levels of variety declaration indicating that less intensive testing strategies sufficiently reduced adventitious presence of GM. The risk premium also slightly declined from 2.42 c/bu in the base case to 2.34 c/bu, 2.26 c/bu, and 2.19 c/bu for the low, moderate, and high variety declaration case, respectively. At the importer, Non-GM flows generally increased for higher levels of variety declaration, and the probability of rejection generally decreased although the moderate case experienced a slight increase and decrease in probability of rejection and Non-GM flows, respectively.

Parametric Sensitivities

Sensitivities on parametric variables assess impacts to optimal testing strategies, risks, and costs from system changes including risk aversion of handlers/shippers and the rate of GM adoption. The successive sections examine these changes and compare variations with the base case.

- **Risk Aversion (η).** The risk parameter η was varied from 0.5 in the base case to 0.4 and 0.9 to represent less risk averse and more risk averse handlers/shippers, respectively. The optimal testing strategy intensified as risk aversion increased indicating that more risk averse firms prefer testing to quality loss. Correspondingly, testing costs progressively increased and quality loss steadily decreased for higher levels of η. The risk premium required to compensate handlers/shippers decreased from 2.42 c/bu in the base case to 1.63 c/bu for the less risk averse case and increased to 3.28 c/bu for the more risk averse case. The probability of rejection at the importer increased for the less risk averse case and decreased for the more risk averse case. Total costs across all bushels and Non-GM bushels declined for higher levels of η. Across Non-GM bushels, the less risk averse case had a total cost of 43.3 c/bu compared to 15.83 c/bu the base case and 9.19 c/bu for the more risk averse case. The large disparities resulted from quality loss and were further exacerbated by the percentage of Non-GM flows at the importer, which significantly increased for higher levels of risk aversion.

- **GM Adoption.** Varying levels of GM adoption could proliferate in the case of GM wheat depending upon import restrictions, agronomic benefits, and consumer preferences. GM adoption rates were varied for no variety declaration and variety declaration scenarios to identify system implications.

  Three cases including 10%, 25%, and 30% GM adoption were examined with no variety declaration; however, only 10% and 25% cases provided feasible results. The 10% case employed a less intensive testing strategy that resulted in lower testing costs, quality loss, and total costs across all and Non-GM bushels. In addition, the percentage of Non-GM flows increased from 48% in the base case to 57.8%. The 25% case tested the same as the base case and resulted in higher testing cost, quality loss, and total cost when measured across Non-GM bushels, partially due to 39.1% of flows being Non-GM at the importer. The risk premium and probability of rejection at the importer both increased for higher GM adoption rates, indicating that it becomes more challenging to remove adventitious presence of GM in a no variety declaration. The 30% case was unable to achieve segregation of Non-GM and GM flows at a cost less than the underlying value of the commodity. This reveals that GM adoption rates greater than 25% necessitate a system of variety declaration with contract mechanisms.

  The rate of GM adoption with variety declaration was varied to 25%, 50%, 60%, 70%, and 75% to simulate impacts on the system. The 75% case was infeasible indicating that a GM adoption rate greater than 70% would necessitate an alternate system of testing and segregation and/or IP to adequately maintain segregation of GM and Non-GM flows. As the rate of GM adoption increased, testing was less intensive and quality loss generally increased with the exception of the 25% case where quality loss decreased. Total costs across all and Non-GM bushels generally increased as the GM adoption rate increased except for the 25% case where total cost declined. The risk premium initially decreased for the 25% and 50% cases, and then increased for the 60% and 70% cases because disutility was lower for 25% and 50%, and higher for 60% and 70% compared to the base case. The probability of rejection at the importer initially decreased for the 25% case and then progressively increased for 50%, 60%, and 70% cases. Conversely, the percent of Non-GM flows at the importer increased for the 25% case and then progressively decreased for 50%, 60%, and 70% cases. The rationale for lower importer rejection, risk premium, and total costs for the 25% case and lower risk premium for the 50% case may be attributed to discrete choice and utility theory.

Implications

Development and commercialization of genetically modified crops continues to challenge the current functions and operations of the grain marketing system. With the anticipated commercialization of GM wheat, these issues remain increasingly important. The research defines several relationships between optimal testing strategies, risks, costs, and different variables impacting the dual marketing system. The impact of stochastic, strategic, parametric, and other variables on the optimal testing strategies, risks, and costs are shown and evaluated. Implications for public and private sectors are summarized in the following sections.

There are several implications for the public sector. First, a system of testing and segregation can efficiently provide end-users differentiated grain shipments to meet consumer requirements at a low cost. While nil tolerances are unattainable, GM content can reasonably be assured for current import specifications of 0.5% or above. Second, grain uniformity and quality deviations existing in the marketplace are minimized due to quality loss applied at the end-user. Sellers view deviations from zero percent GM contamination as an implicit cost; thus, more rigorous testing ensues thereby reducing GM content in Non-GM shipments. Third, consumer differentiation among value-added products necessitates a system of testing and segregation to properly allocate Non-GM and GM flows.

Several private sector implications exist. First, a system of testing and segregation drastically reduces cost when compared to an IP alternative. IP entails increased monitoring and documentation through production, storage, transportation, and handling phases. Second, with rapid advancements in testing technology, costs and risks will progressively decrease. Third, risk premiums evolve to compensate grain handlers for added risks of a dual marketing system versus a Non-GM system. Fourth, adventitious presence resulting from variety risks will encourage grain handlers to adopt a system of contract mechanisms. Fifth, additional penalties (A_O) encourage handlers/shippers to test more intensively to avoid quality losses. Sixth, import tolerance defines testing strategy and accompanying costs and risks. Seventh, more and less risk averse grain handlers tradeoff definite testing costs for indefinite quality loss. Eighth, the rate of GM adoption has a significant bearing of the viability of the defined system of testing and segregation. With no variety declaration, GM adoption of greater than 25% necessitates variety declaration mechanisms. With variety declaration, GM adoption of greater than 70% provides cost prohibitive results and thus necessitates an alternate form of testing and segregation and/or IP. Ninth, delivery to a domestic user requires a system of variety declaration.

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